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Philip L. Richardson
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Technical Report

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Philip L. Richardson

Philip L. Richardson, Chair
Department of Physical Oceanography

Abstract

Neutrally buoyant SOFAR floats at nominal depths of 800 m, 1800 m, and 3300 m were tracked acoustically for 3.7 years in the vicinity of the western boundary and the equator of the Atlantic Ocean. Trajectories and summaries from the whole experiment are shown along with detailed trajectories from the second setting of the listening stations, October 1990 to September 1992. Some highlights are mentioned below.

Trajectories at 1800 m revealed a swift, narrow southward flowing deep western boundary current (DWBC) extending from 7N across the equator. Two floats directly crossed the equator in the DWBC and went to 10S. Two other floats left the DWBC near the equator and drifted eastward. Three floats entered the DWBC from the equatorial current system and drifted southward. No obvious DWBC or swift equatorial currents were observed by the 3300 m floats.

The 800 m floats plus some surface drifters measured seven anticyclonic eddies as they translated northwestward along the coast of South America in a band from the equator to 12N. One of the floats (28) entered the Caribbean where tracking stopped. This float was again tracked as it drifted across the mid-Atlantic Ridge and entered the Canary Basin near 34N 28W after a gap of 2.7 years. We infer that this float went westward through the Caribbean and northeastward in the Gulf Stream. Float 17 drifted northward from 10N to 22N in an eastern boundary current off the coast of West Africa. Floats between 6N–6S (roughly) drifted long distances zonally in the equatorial current system.

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1 Introduction

This report describes SOFAR float trajectories in the equatorial Atlantic at depths of 800 m in the Antarctic Intermediate Water and at 1800 m and 3300 m in the North Atlantic Deep Water. The fundamental issue investigated is the exchange of water between the North and South Atlantic. Water mass properties including freon imply that deep western boundary current (DWBC) water splits near the equator, with part flowing eastward along the equator and part continuing southward along the western boundary. It is not known to what extent the tongue of freon lying along the equator near 1700 m is due to advection or to enhanced mixing. Thus a secondary issue investigated is the nature of the connection between the DWBC and flow along the equator.

The DWBC is the major pathway by which cold deep water flows southward into the South Atlantic and, eventually, into the Pacific and Indian Oceans. The warm upper layer in the Atlantic, including the intermediate water, is thought to flow northward in compensation for the deep water. Schmitz and Richardson (1991) identified 13×10^6 m^3/s of upper level water from the South Atlantic flowing northward across the equator into the Gulf Stream. Neither flow had previously been directly measured crossing the equator. This large-scale thermohaline circulation results in a northward heat flux through the Atlantic which is important for world climate. An improved understanding of the thermohaline circulation and its variability is required in order to design a scheme to measure variations in the meridional flux of heat in the oceans and variations in climate.

The results described here are a continuation of an experiment begun in January 1989. An earlier technical report (Richardson *et al.*, 1992) and two papers (Richardson and Schmitz, 1993; Richardson *et al.*, 1994) describe results from the first 21 months of data. This report summarizes the whole experiment

and shows detailed trajectories from the last 24 months of data, October 1990–September 1992.

The main results are the first long-term float trajectories in the tropical Atlantic. New information is revealed about the thermohaline circulation, including a swift southward flowing DWBC at 1800 m that at times crosses the equator and at other times feeds into an eastward equatorial current. The floats give a first Lagrangian view of the deep equatorial current system and its connections to the currents along the western boundary. In the 800 m level, northward drift of floats is observed in anticyclonic eddies along the western boundary and also in an eastern boundary current off Africa.

The report is divided into two main parts. The first follows this introduction and summarizes the whole experiment. The second part consists of two appendices that show some summary composites of trajectories (Appendix A) and plots of individual floats (Appendix B).

2 Methods

During January and February 1989, 48 SOFAR floats were launched in the tropical Atlantic, 14 at 800 m in the intermediate water, 15 at 1800 m and 15 at 3300 m in the deep water, and 4 by J. Price as engineering tests of a Bobber float at depths near 300 db and 650 db (Figure 1, Table 1). The floats were tracked acoustically from January 1989 to September 1992 by means of an array of six moored autonomous listening stations (Figure 1, Table 2). Thirty-one of the floats were launched along a line spanning the Atlantic between 6N and 11N, with closest spacing between floats near the western boundary off French Guiana, where the velocity is swiftest. Seventeen floats were launched along the equator in the west, where meridional flow is thought to cross the equator and eastward flow along the equator originates. Thus the whole width of the Atlantic between

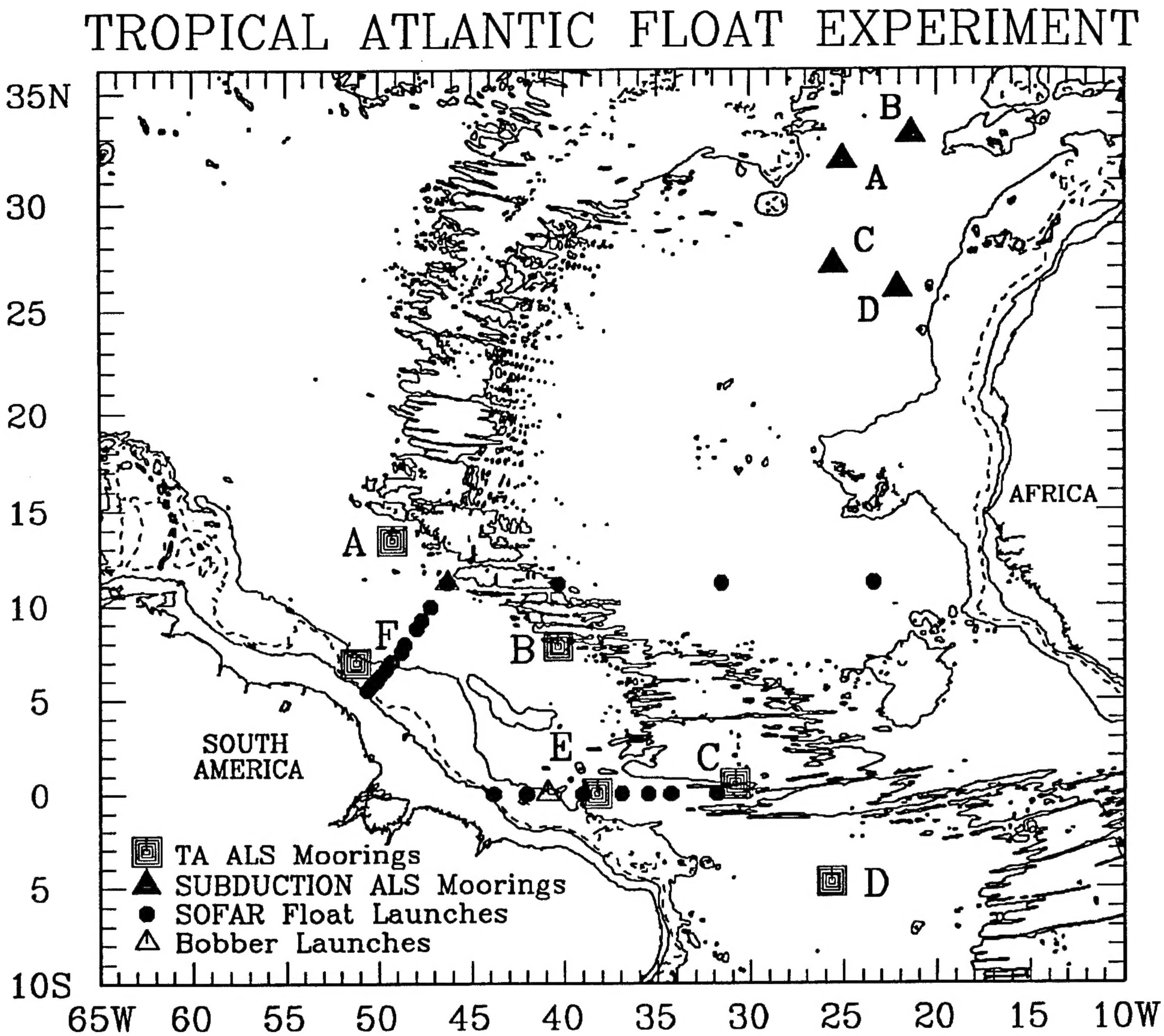

Figure 1: Launch locations of SOFAR floats (dots) in January and February 1989 and locations of Autonomous Listening Stations (ALS's) used to track the floats during October 1990–September 1992. The squares show the tropical Atlantic ALS sites and the triangles show the Subduction experiment ALS sites. Depth contours are from Uchupi (1971): 200 m and 4000 m are solid lines, 2000 m is dashed.

Table I Summary of SOFAR Float Data

Bobbers	Depth	Start Date	Start Lat	Start Lon	End Date	End Lat	End Lon	Limits Lat	Limits Lon	Days Tracked	Days Heard	Average Velocities		EKE
TB 12	300	890209	11.20	-46.31	890714	7.30	-44.82	6: 12	-48: -43	156	156	1.21	-3.17	103.82
TB 62	350	890126	0.18	-40.77	890827	1.42	-42.58	0: 4	-43: -34	214	221	-1.10	0.74	108.41
TB 63	650	890126	0.14	-40.76	910103	10.27	-48.38	-2: 12	-51: -40	708	1298	-1.38	1.84	62.20
TB 81	625	890209	11.19	-46.30	891230	9.94	-59.60	8: 12	-60: -46	325	333	-5.21	-0.49	45.30
800 m														
TA 16	800	890127	0.04	-43.90	920127	-5.32	-12.05	-8: 1	-44: -12	1096	1205	3.75	-0.64	78.07
TA 17	800	890217	11.22	-23.18	930520	23.28	-24.28	8: 24	-26: -16	1496	1570*	-0.09	0.99	44.45
TA 18	800	890216	11.16	-31.64	920918	11.89	-53.93	9: 15	-54: -31	1311	1322*	-2.16	0.07	23.08
TA 19	800	890211	11.11	-40.36	920517	9.57	-24.22	4: 12	-42: -23	1174	1240	1.72	-0.17	51.32
TA 20	800	890208	7.52	-48.73	920505	9.63	-45.31	5: 13	-53: -41	1140	1201	0.37	0.23	36.23
TA 21	800	890208	5.85	-50.51	900928	5.74	-48.96	5: 10	-54: -46	598	634	0.32	-0.03	72.33
TA 22	800	890208	6.51	-49.63	920522	9.85	-56.51	5: 17	-61: -49	1200	1200	-0.74	0.35	94.58
TA 23	800	890207	6.04	-50.24	910212	9.48	-57.89	5: 12	-60: -50	736	736	-1.33	0.59	48.51
TA 24	1125	890125	0.10	-31.34	920918	-0.89	-10.81	-3: 2	-32: -2	1333	1344*	1.99	-0.10	49.05
TA 25	800	890207	5.55	-50.67	910410	-2.46	-37.20	-3: 10	-52: -37	793	796	2.19	-1.30	116.55
TA 26	800	890209	9.30	-47.77	920921	7.34	-35.31	1: 11	-48: -12	1321	1329*	1.21	-0.19	72.60
TA 28	800	890125	0.06	-39.22	930514	29.29	-25.49	0: 35	-62: -22	594	1596*	1.08	2.39	155.65
TA 31	800	890126	0.09	-42.03	920921	-1.18	-29.78	-3: 4	-48: -23	1335	1574*	1.18	-0.12	114.87
TA 34	800	890125	-0.14	-35.40	890725	-3.67	-19.41	-5: 0	-36: -19	182	229	11.40	-2.45	98.48
1800 m														
TA 01	1800	890127	-0.46	-38.78	920920	0.57	-16.87	-4: 2	-39: -13	1333	1342*	2.12	0.10	37.20
TA 02	1800	890209	6.77	-49.45	920325	-16.29	-34.85	-17: 9	-52: -31	947	1238	1.63	-2.59	83.77
TA 04	1800	890211	11.11	-40.35	920922	6.42	-35.75	5: 12	-53: -35	1320	1387*	0.46	-0.45	29.62
TA 05	1800	890207	5.60	-50.29	920922	3.17	-31.88	-2: 6	-51: -28	1324	1331*	1.80	-0.25	50.83
TA 06	1800	890127	0.12	-41.89	920918	-8.72	-31.23	-10: 3	-43: -26	792	1342*	1.03	-0.85	64.34
TA 07	1800	890216	11.23	-23.15	910506	11.43	-23.38	11: 13	-26: -23	810	814	-0.04	0.04	1.63
TA 08	1800	890208	7.59	-48.80	910726	-10.91	-34.20	-12: 11	-53: -32	899	902	2.09	-2.63	69.15
TA 09	1800	890127	-0.24	-43.39	920804	-3.80	-37.13	-4: 2	-44: -18	1286	1342*	0.64	-0.37	53.40
TA 10	1800	890207	5.32	-50.41	890329	4.41	-48.60	4: 6	-51: -48	51	1313	4.81	-2.53	41.38
TA 11	1800	890210	11.23	-46.13	911201	9.64	-46.18	7: 12	-49: -44	1025	1025	-0.01	-0.20	9.69
TA 12	1800	890215	11.14	-31.61	920523	10.58	-36.41	9: 12	-37: -29	1194	1204	-0.51	-0.06	3.62
TA 13	1800	890209	9.29	-47.72	920918	10.30	-51.90	2: 12	-55: -45	1318	1329*	-0.41	0.10	57.90
TA 14	1800	890207	5.95	-50.07	920921	-0.16	-40.77	-2: 9	-52: -34	1323	1331*	0.91	-0.60	101.20
TA 15	1800	890123	-0.03	-31.87	910909	-5.08	-34.54	-6: 2	-40: -31	960	1255	-0.36	-0.68	15.94
3300 m														
TA 30	3300	890129	0.25	-38.96	920918	-10.15	-24.90	-11: 1	-41: -24	1175	1340*	1.36	-1.00	16.86
TA 35	3300	890124	-0.03	-34.25	920911	1.50	-33.51	-1: 2	-40: -32	1267	1345*	0.07	0.15	13.19
TA 36	3300	890208	8.00	-48.66	911211	6.28	-48.55	4: 11	-53: -47	306	1037	0.01	-0.21	29.07
TA 38	3300	890124	-0.02	-31.78	900521	-1.46	-34.18	-3: 0	-35: -29	483	500	-0.64	-0.38	6.42
TA 39	3300	890208	6.69	-49.56	891205	5.52	-46.19	5: 9	-50: -45	301	1330*	1.43	-0.52	21.00
TA 40	3300	890208	7.06	-49.26	920218	10.48	-44.78	7: 11	-50: -44	697	1106	0.52	0.40	8.98
TA 42	3300	890207	6.27	-49.88	891021	7.82	-50.93	6: 9	-51: -48	257	257	-0.51	0.77	12.34
TA 44	3300	890213	11.23	-40.31	910906	9.06	-47.25	8: 12	-49: -40	260	997	-0.94	-0.30	4.64
TA 45	3300	890124	0.09	-36.93	891017	-1.13	-36.71	-2: 1	-37: -35	267	852	0.11	-0.60	10.89

TABLE 2

MOORED AUTONOMOUS LISTENING STATIONS

ALS SITE	ALS #	ALS DEPTH (m)	LAUNCH DATE yymmdd	RECOVERY DATE yymmdd	LATITUDE deg N	LONGITUDE deg W
		Tropical Atlantic 1989 - 1990				
A	160	750	890109	901030	13.453	49.260
B	161	823	890112	901102	7.845	40.345
C	162	760	890117	901119	0.519	30.848
D	163	819	890119	901108	-4.711	25.667
E	164	812	890123	901112	0.034	38.276
F	159	825	890108	901028	6.980	51.235
		Tropical Atlantic 1990 - 1992				
A	166	798	901031	920921	13.463	49.246
B	167	808	901102	920925	7.873	40.376
C	169	834	901111	921002	-0.412	32.595
D	168	792	901109	921006	-4.711	25.674
E	170	801	901112	920927	-0.113	38.316
F	165	820	901028	920923	6.946	51.212
		Subduction 1991 - 1993				
A	171	1626	910507	930612	31.938	25.037
B	172	1616	910512	930611	33.132	21.378
C	173	1426	910528	930520	27.114	25.485
D	174	1524	910530	930521	25.975	22.086

Table 3: Summary of float lifetimes.

Float Depth	Bobbers	800 m	1800 m	3300m	All
Number of floats launched	4	14	15	15	48
Number of floats tracked	4	14	14	9	41
Number of floats lasted 44 mos	0	6	7	3	16
Median time to failure (years)	1.4	3.3	3.7	2.8	3.4
Average float years heard	1.4	3.1	3.4	2.7	2.9
Average float years tracked	1.0	2.8	2.9	1.5	2.4
Total float years heard	5.5	43.7	47.0	24.0	120
Total float years tracked	3.8	39.2	39.9	13.7	96.7

French Guiana and West Africa was instrumented with floats, although sparsely in the eastern region.

a) Float lifetimes

Of the 48 floats launched 42 were heard by the ALS's and 41 were tracked (Figures 2 and 3, Table 3). The signal from one float was garbled by a test signal in the ALS's. Four of the 3300 m floats failed at launch and were never heard, and two others were not heard because of a reduced acoustic range at 3300 m. Sixteen floats were heard to the end of the ALS records, a length of 44 months, and four of these floats were heard longer than this by the Subduction array of ALS's in the Canary Basin. The prototype Bobber floats had a shorter design life and died before the end of the experiment. Six out of the nine tracked 3300 m floats died or were not heard at the end of the ALS records. Roughly half (46%) of the 800 m and 1800 m floats were heard at the end. The median time to failure of all floats is 3.4 years and for the 800 m and 1800 m floats 3.6 years, close to the length of the experiment, 3.7 years. Failure is defined to be when a float was no longer heard by any ALS, excluding the six 3300 floats that were never heard at launch.

The total number of float years heard is 120 and the float years tracked is 97. Tracking times are less than the heard times because (a) the 3300 m floats gradually sank to the lower limit of the sound channel and encountered shorter

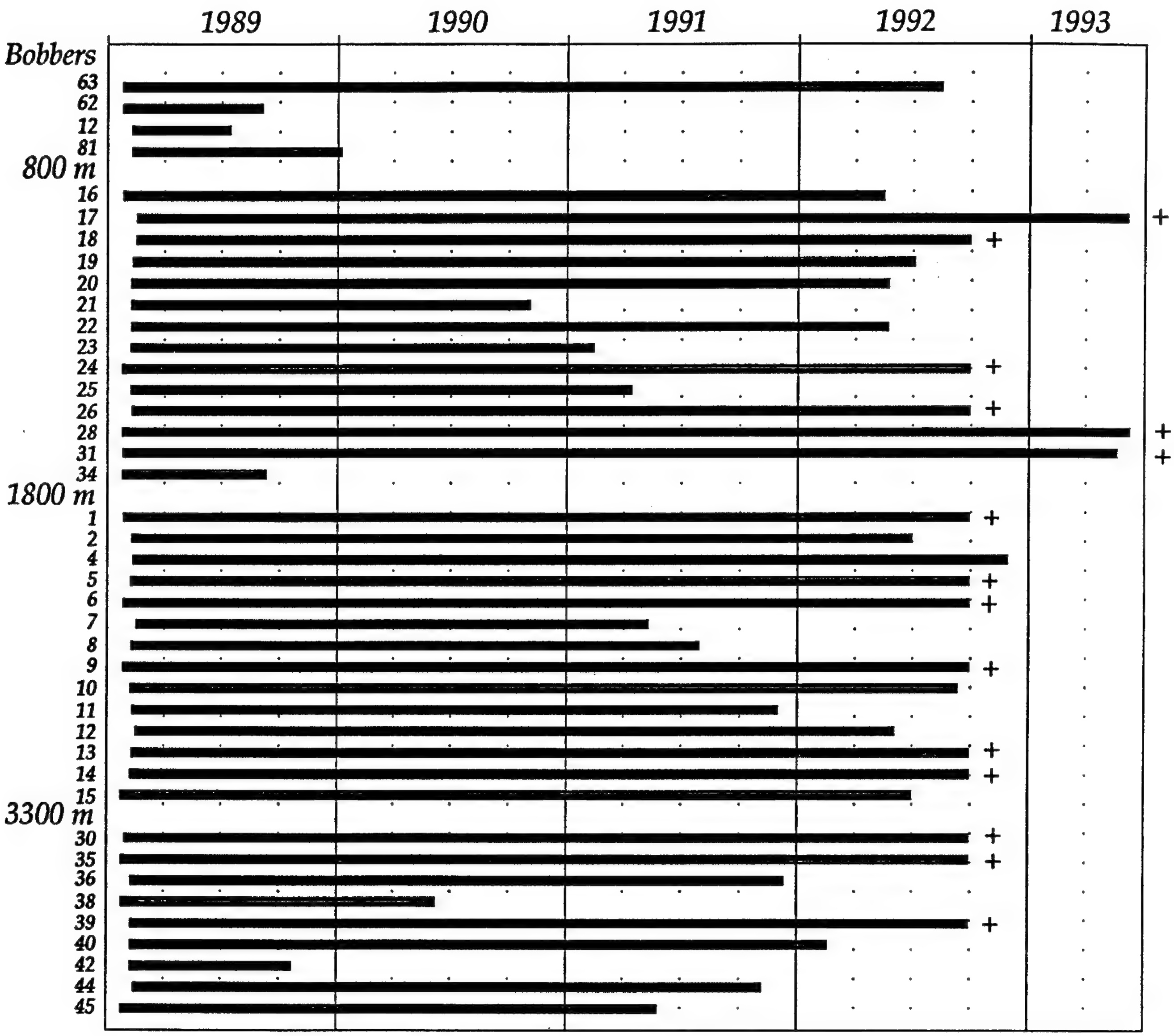

Figure 2: Summary of times each float was heard by the ALS's. A plus sign indicates that the float was heard at the time the ALS's were retrieved.

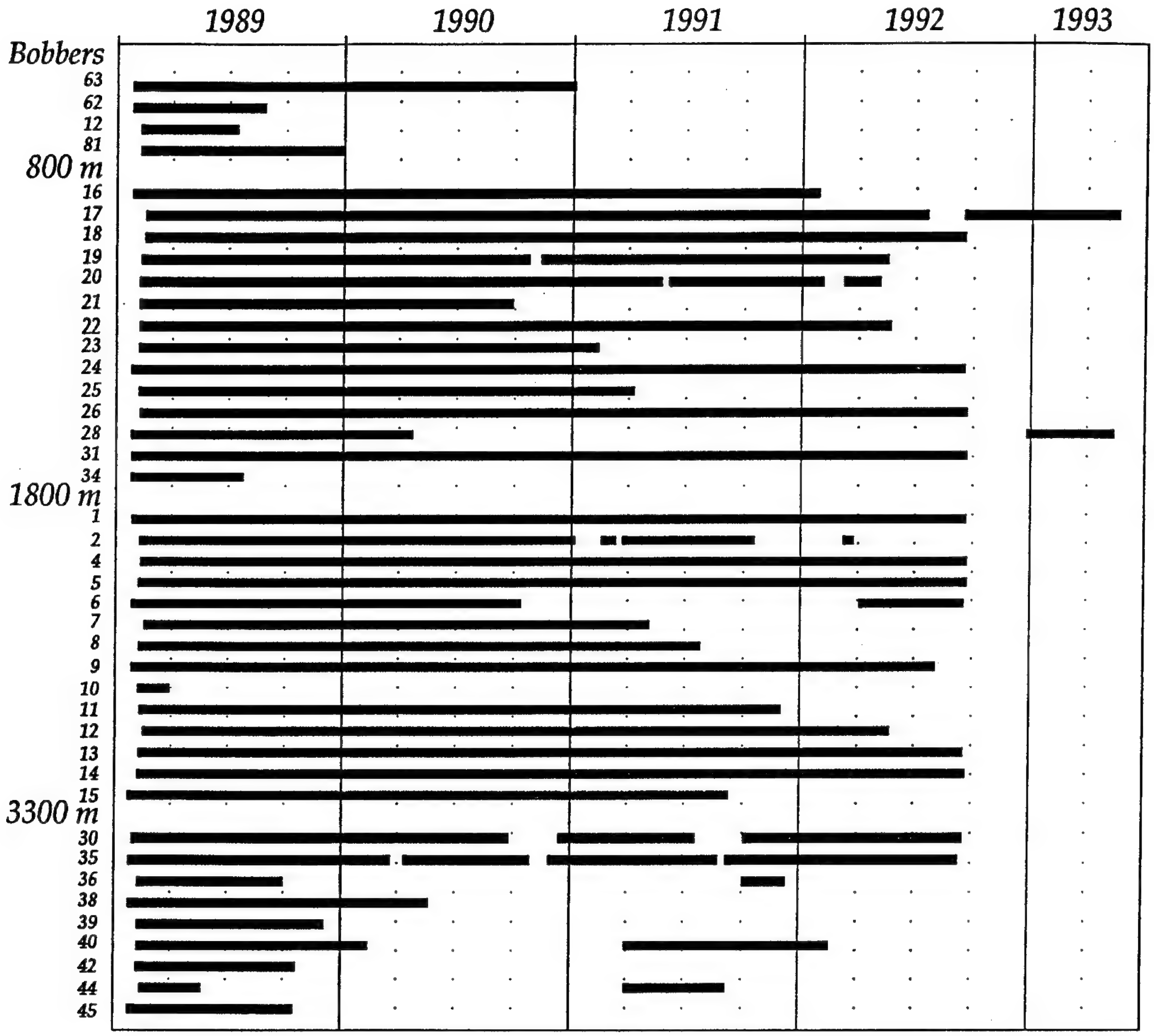

Figure 3: Summary of times each float was tracked using the ALS data.

acoustic ranges, (b) some floats were heard by only one ALS at the end (two or more are needed for tracking), (c) some float signals were blocked by topography, and (d) three 1800 m floats grounded and did not move for long times.

b) Temperature and pressure

All floats except the four Bobbers failed to transmit correct temperature and pressure data after they had equilibrated, and they also failed to activate their buoyancy control which would have kept them at constant pressure. In order to estimate equilibrium depths at sea, two floats at each level were followed acoustically from the ship as they sank. The floats at the 800 db level equilibrated at 795 db and 800 db; those at the 1800 db level equilibrated at 1825 db and 1770 db. Two deep floats were followed down to 2570 db and 2860 db where their telemetry stopped. An extrapolation of their data to equilibrium pressure showed that the floats reached 3255 db and 3250 db. In the following, the three equilibrium pressures will be referred to as 800 m, 1800 m, and 3300 m, but individual floats could have differed from these nominal depths.

Without active ballasting, SOFAR floats gradually sink due to the slow deformation of their pressure housing, which is aluminum for 800 m and 1800 m floats and glass for 3300 m floats. In order to estimate this sink rate, all available historical float data were examined. Ten aluminum floats and five glass floats were found to give reliable estimates of the long-term sink rate (see Richardson *et al.*, 1992). The mean sink rate and standard error of aluminum floats was 0.37 ± 0.05 db/d. No obvious relationship was seen between their sink rate and the pressure level, which suggests that the mean sink rate is appropriate for the two depths. The mean rate implies that the 800 m and 1800 m floats would have sunk around 500 m over the 44 months discussed here. The mean sink rate of the glass floats was 0.62 ± 0.11 db/d, which implies that the 3300 m floats would have sunk around 340 m over their mean tracked lifetime of 18 months. The gradually

decreasing acoustic range observed with some 3300 m floats is inferred to be due to their gradual sinking toward the lower limit of the sound channel.

c) Groundings

Three 1800 m floats on the inshore edge of the DWBC drifted into water shallower than their equilibrium depth and probably dragged along the sea floor. Float 10 clearly went aground after 51 days and remained stuck for the rest of the experiment. Float 6 was aground for 14 months near 3S. Float 8 was aground for five months and drifted southward very slowly (~1 cm/sec) parallel to the topography between 5.0S to 6.5S. Charts differ considerably about the exact bathymetry which makes it difficult to estimate depths of the grounded floats.

The ability of a float to drag upslope along the sea floor into water shallower than the equilibrium depth can be understood by a simple calculation. Imagine that an 1800 m float is carried upslope along the sea floor to 1300 db where the float is approximately 0.5 kg negatively buoyant. If we assume that the drag of the sea floor on the bottom of a drifting float is equal to this value, that the float remains vertical, and that its drag coefficient is 1.0, then an average water velocity of ~7 cm/sec past the float will provide sufficient drag to force it to drift. Speeds much higher than this were observed in the DWBC near the western boundary.

d) Float tracking and data processing

The floats transmitted an 80 sec 250 Hz acoustic signal once per day. Float clock corrections and positions were calculated from the times of arrival of signals received at the moored listening stations. Spurious positions were edited manually, gaps less than 10 days long were linearly interpolated, and the resulting time series were smoothed by means of a Gaussian shaped filter (of weights 0.054, 0.245, 0.403, 0.245, and 0.054) to reduce position errors and tidal and inertial fluctuations. Velocity along trajectories was calculated at each final position by

means of a cubic spline function. The average accuracy of a fix was estimated to be less than 10 km based on a comparison of float launch locations and first tracked positions.

3 Results

a) 800 m floats

Summary plots of the trajectories and displacement vectors of the 800 m floats are given in Figure 4. New results concerning the 800 m floats are briefly described below. An additional North Brazil Current retroflection eddy was measured by float 22 from March–May 1992 (see Figures 5, 6 and 7). This trajectory was included in the paper by Richardson *et al.* (1994).

Float 28 which entered the Caribbean in April 1990 was tracked from December 1992 to April 1993 by a listening station array located in the Canary Basin. We hypothesize that float 28 drifted westward through the Caribbean, northeastward in the Gulf Stream and eastward across the mid-Atlantic Ridge in the North Atlantic Current and Azores Current (Figure 8). We know that this float must have come from the Tropical Atlantic Experiment because of its unique signalling (one transmission per day). No similar signalling was used on other floats which typically transmitted two or three times per day. We also know that float 28 did not go across the gyre as opposed to around it because the listening stations would have heard the float signals at ranges of 2000 km–3000 km. If the real trajectory was similar to our hypothetic one, then the mean speed of the float would have been around 11 cm/sec from April 1990–December 1992. This float drifted the farthest north of all the tropical Atlantic floats, starting on the equator in January 1989 and ending near 30N 25W in April 1993 when the Canary Basin listening stations were retrieved. Thus its total track was over a period of

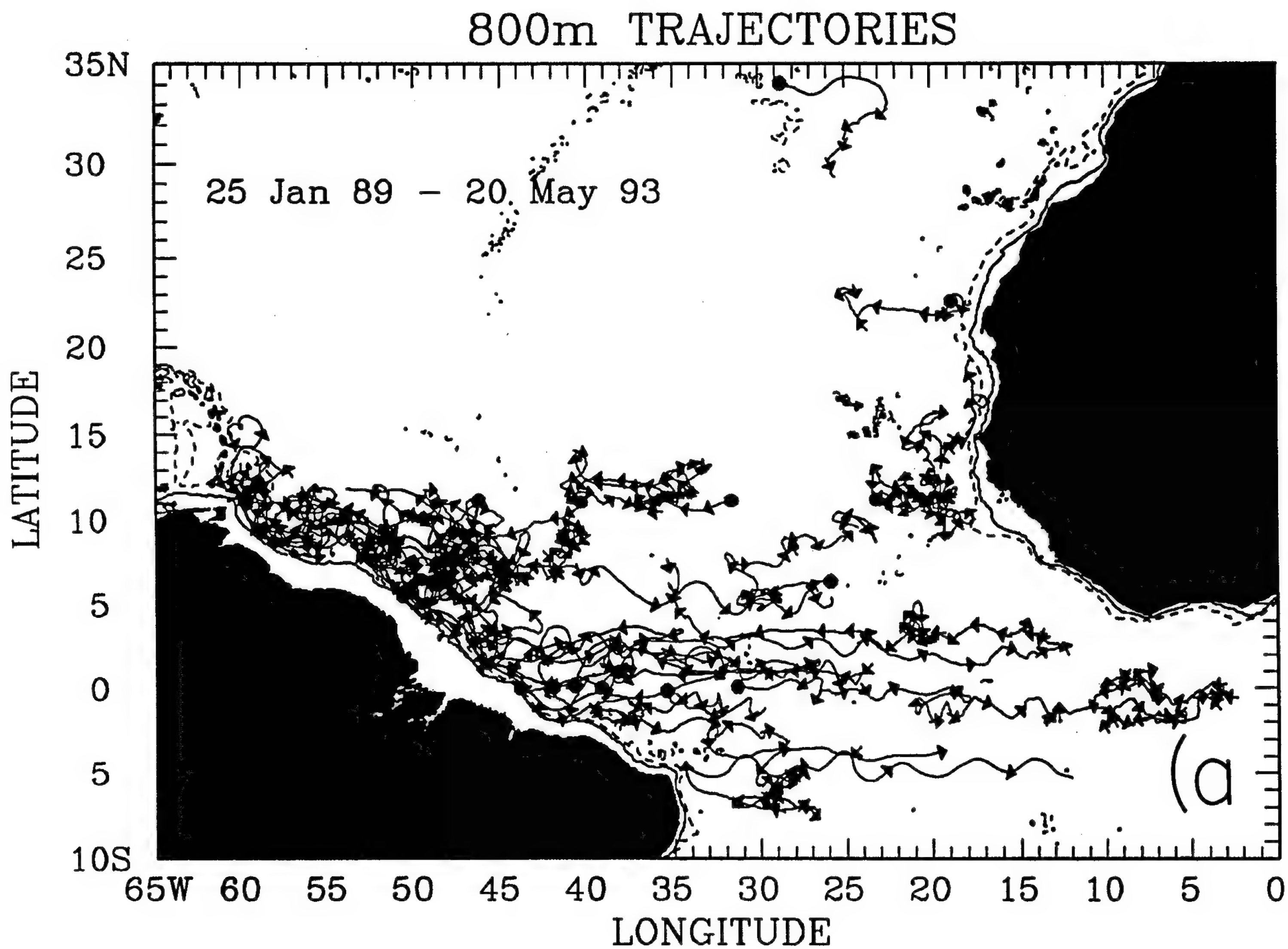

Figure 4a: Summary of 800 m trajectories from January 1989 to September 1992. Four bobber floats at shallower depths were included. Two floats (17, 28) were tracked by a listening station array in the Canary Basin. Arrowheads are spaced at 30-day intervals.

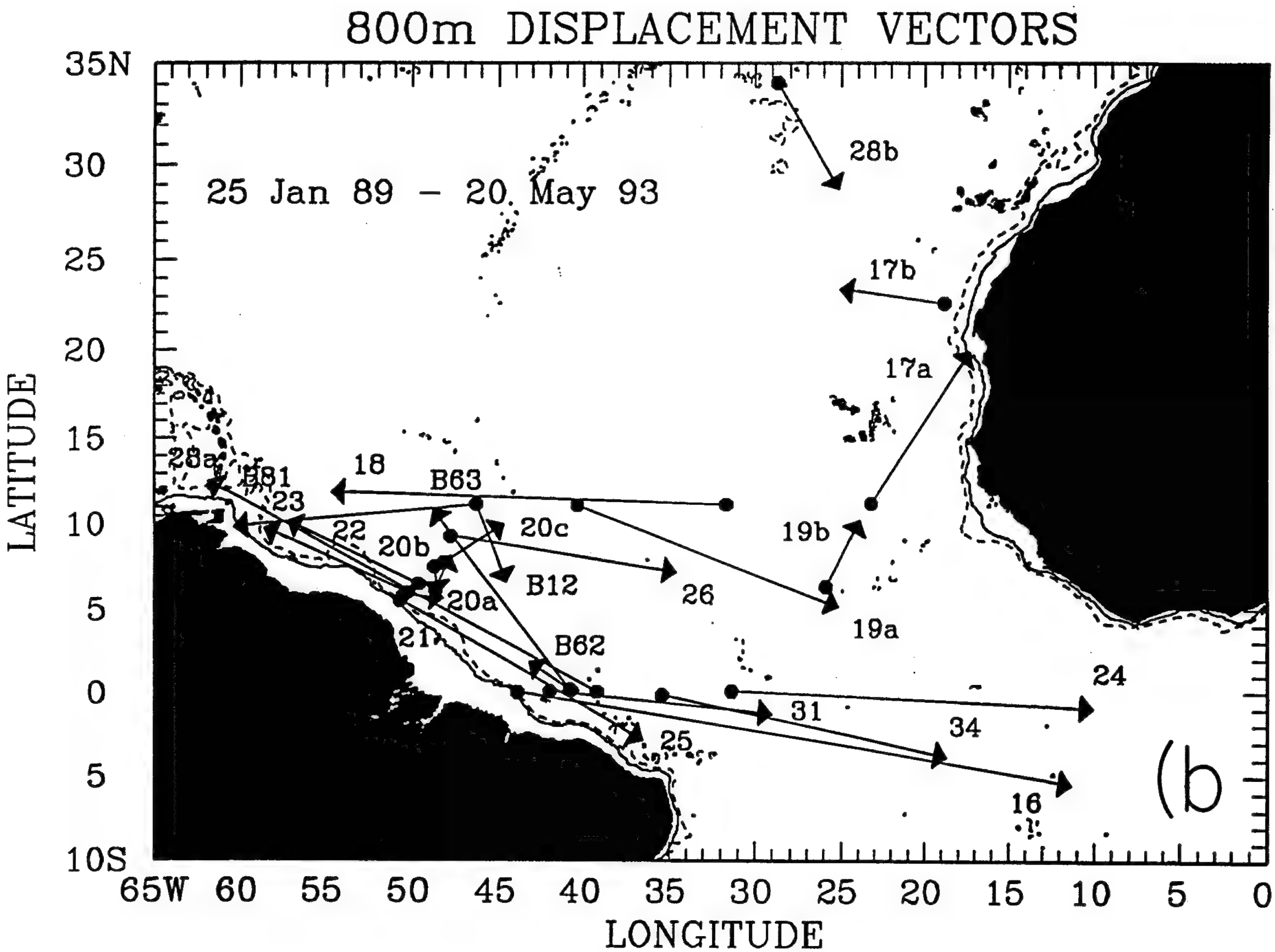

Figure 4b: Displacement vectors for the 800 m floats. More than one vector was given for floats with gaps in their trajectories. Bobber floats are indicated by a B.

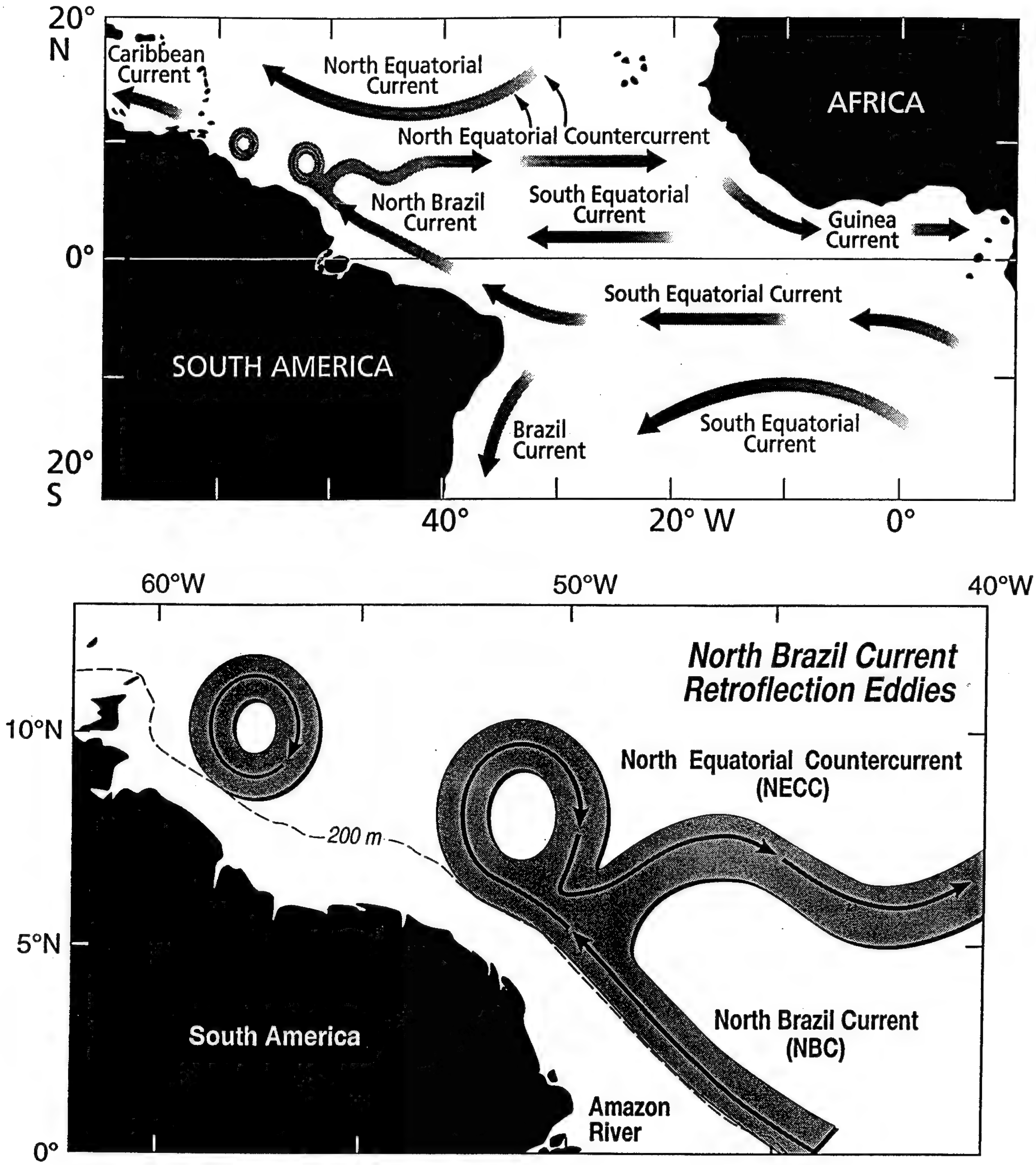

Figure 5: Schematic diagram showing the formation of a North Brazil Current (NBC) retroflection eddy based on CZCS images given by Johns *et al.* (1990). Three to four times each year starting in July the NBC retroflection advances northwestward along the boundary to about 9 to 10N forming a current loop. The sides of the loop come together and the loop pinches off from the main current to form a discrete eddy. As the eddy separates, the retroflection reforms farther south near 5–6N. Retroflection eddies are about 400 km in overall diameter and drift northwestward at 9–10 cm/sec.

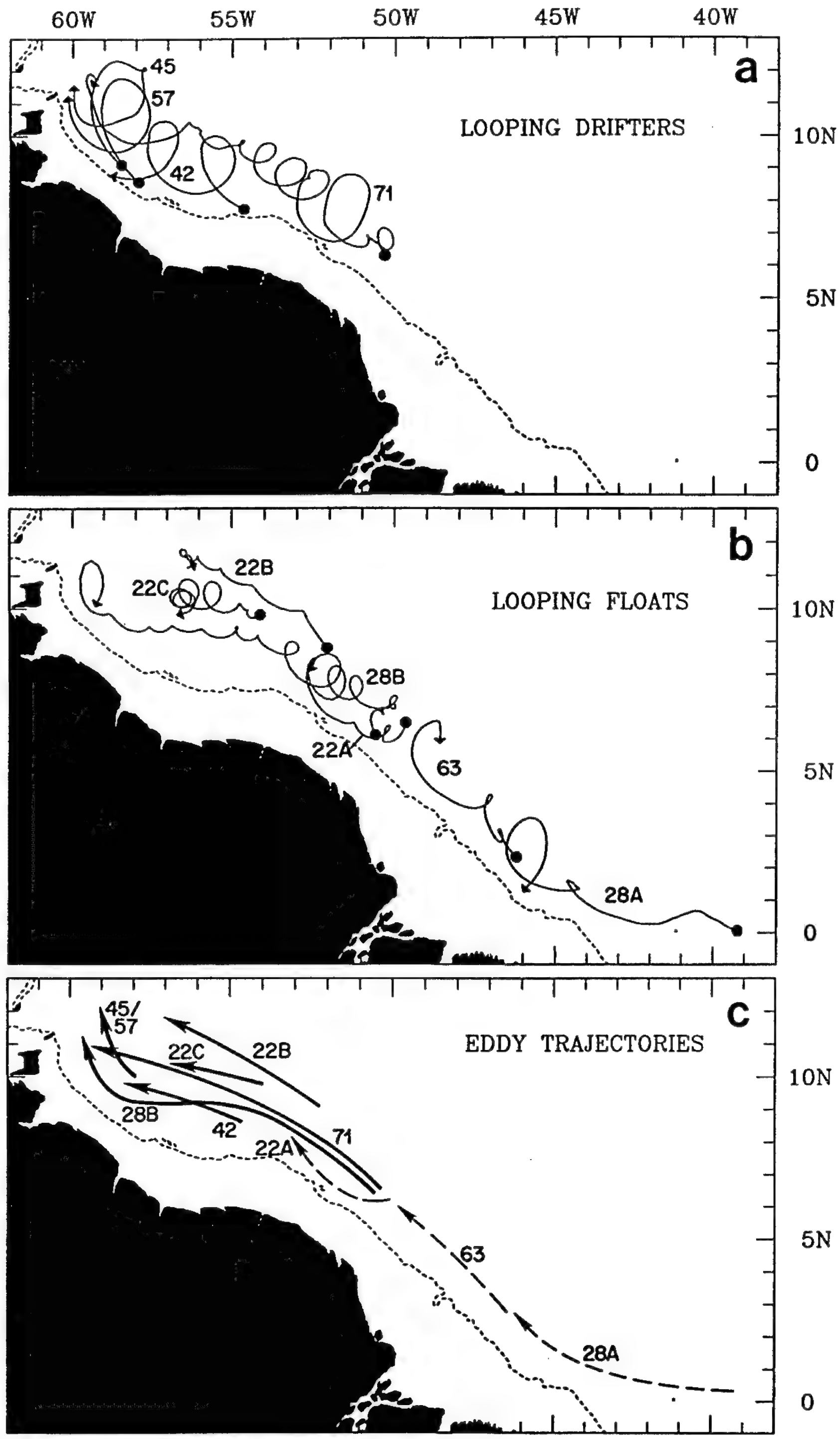

Figure 6: (Top) Composite of four looping surface drifter trajectories during March 1990 to January 1992. (Middle) Composite of six looping float trajectories measured during the period January 1989 to May 1992. (Bottom) Inferred trajectories of the eddy's centers. Solid lines represent retroflection eddies, dashed lines are weaker eddies thought to be different from retroflection eddies. The average translation velocity of the six retroflection eddies is 9 cm/sec toward 296°. Three eddies translated up the boundary during early 1990 (28B, 22B, 47/45). See Richardson *et al.* (1994) for more information concerning these eddies.

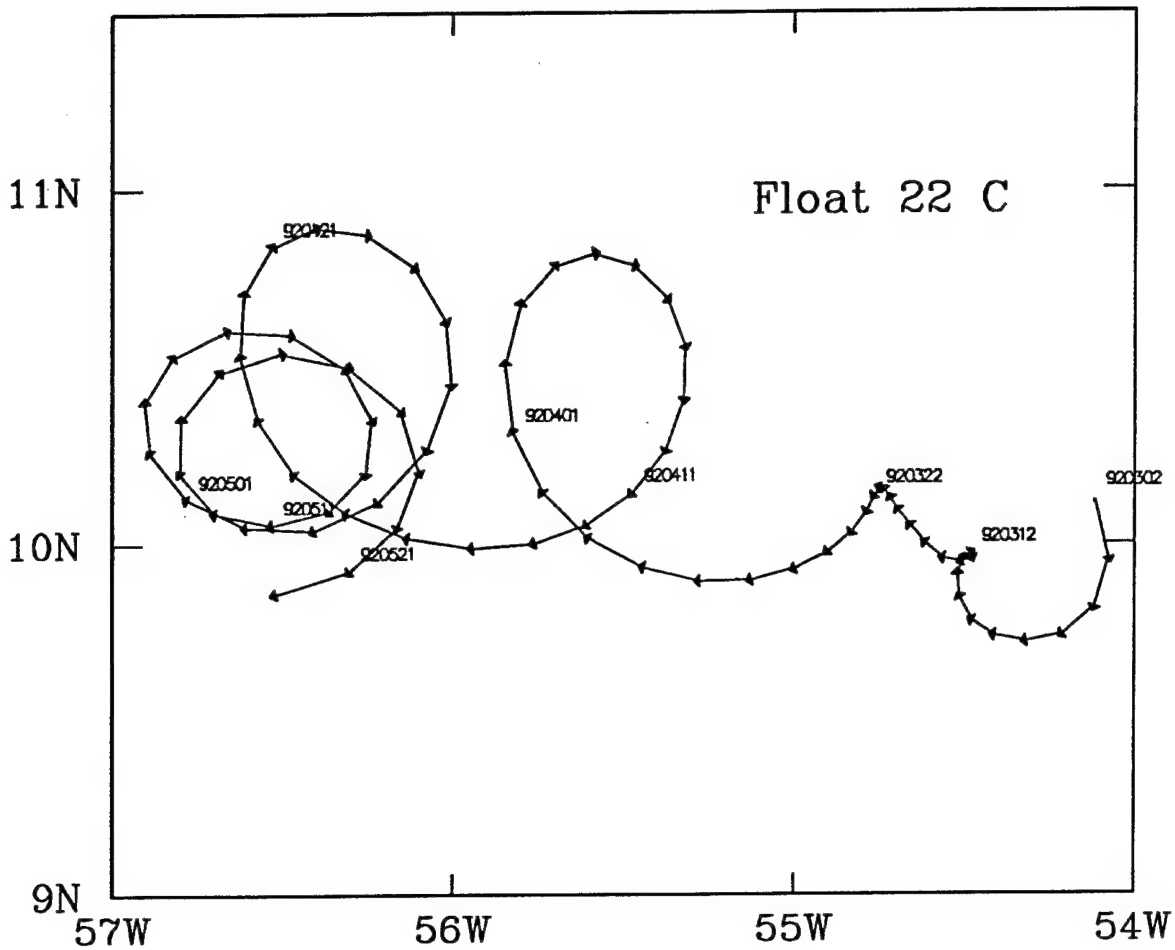

Figure 7: Trajectory of 800 m float 22 as it looped in a North Brazil Current retroflection eddy during March–May 1992. Arrowheads are spaced at daily intervals.

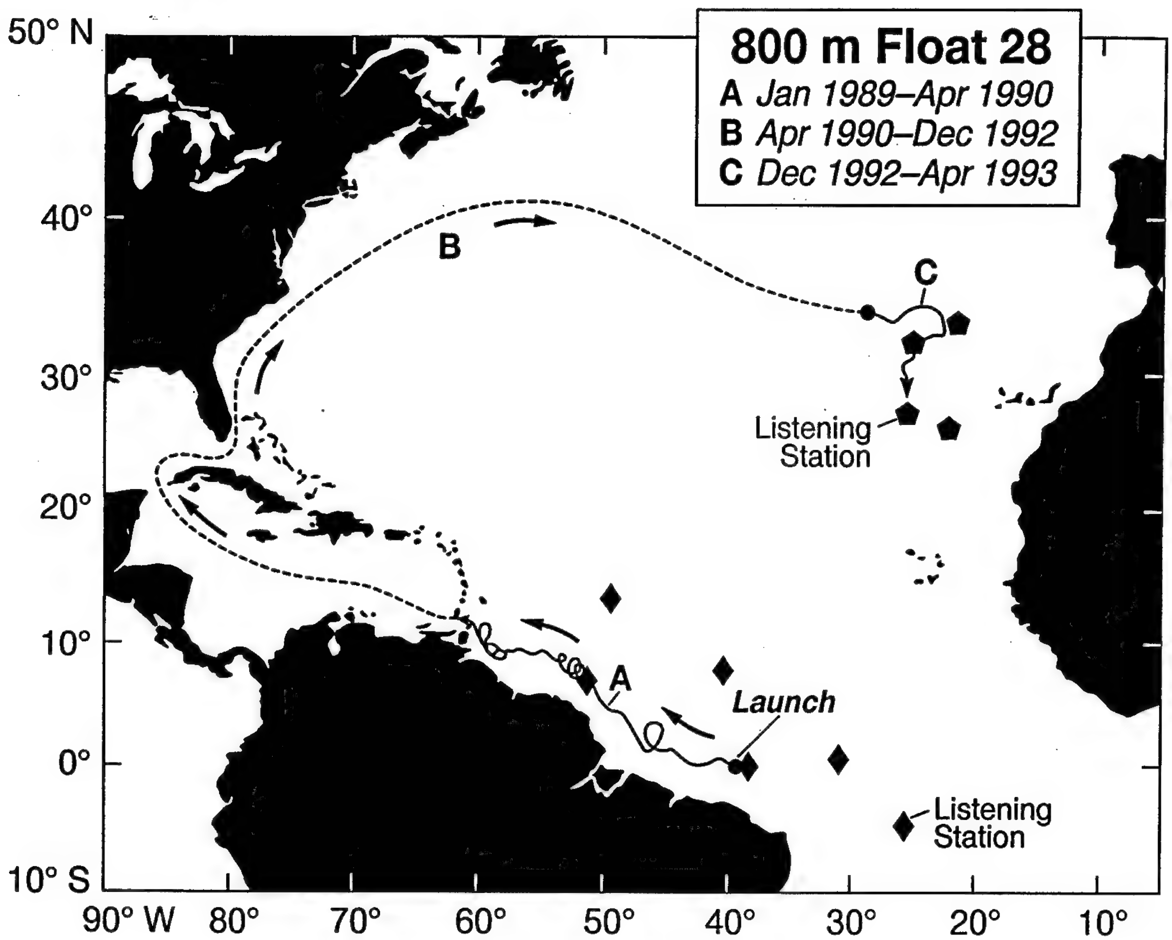

Figure 8: Trajectory of 800 m float 28 as it was tracked by the Tropical Atlantic listening station array from January 1989 to April 1990 and by the Canary Basin array from December 1992 to April 1993. The dashed line is the hypothetical trajectory between April 1990 and December 1992.

4.3 years. This float demonstrates one path of South Atlantic water into the North Atlantic via the Gulf Stream.

Float 28 was observed to equilibrate at 800 m at the time of launch. It must have dragged along the sea floor as it crossed into the Caribbean and through the Straits of Florida as we have observed with 1800 m floats dragging along the continental slope in the DWBC.

Along the western boundary other 800 m floats did not go further north than 16N probably because they gradually sank from Antarctic Intermediate Water located above 1000 m (roughly) into North Atlantic Deep Water below 1000 m (roughly). As they entered the deep water their mean motion would have switched from northward along the boundary to southward. Float 22 followed this general pattern reaching its northernmost point near 16N in November 1990. Afterward it gradually drifted southward except for a final northward displacement in a retroflection eddy. Float 25 also drifted generally southward along the boundary from August 1990 to April 1991.

The second farthest northward drift by an 800 m float was along the west coast of Africa from 10N to 23N a distance of 1400 km (Figure 9). Float 17 was launched near 11N 23W, and over its first two years gradually drifted eastward at 0.8 cm/sec to a point near 10N 18W where it started looping in a cyclonic eddy (Figure 10). The eddy translated almost 600 km northwestward to around 15N where the float came out of the eddy. Float 17 then drifted eastward toward the eastern boundary and then northward along the eastern boundary from 15N to 23N over a 4.1 month period at an average velocity of 8.2 cm/sec. Finally, float 17 drifted westward along 22–23N at 2.8 cm/sec. The long northward drift is good evidence for a rather swift (8 cm/sec) eastern boundary current at estimated depths of 1200–1300 m and within a distance of around 100 km from the continental margin.

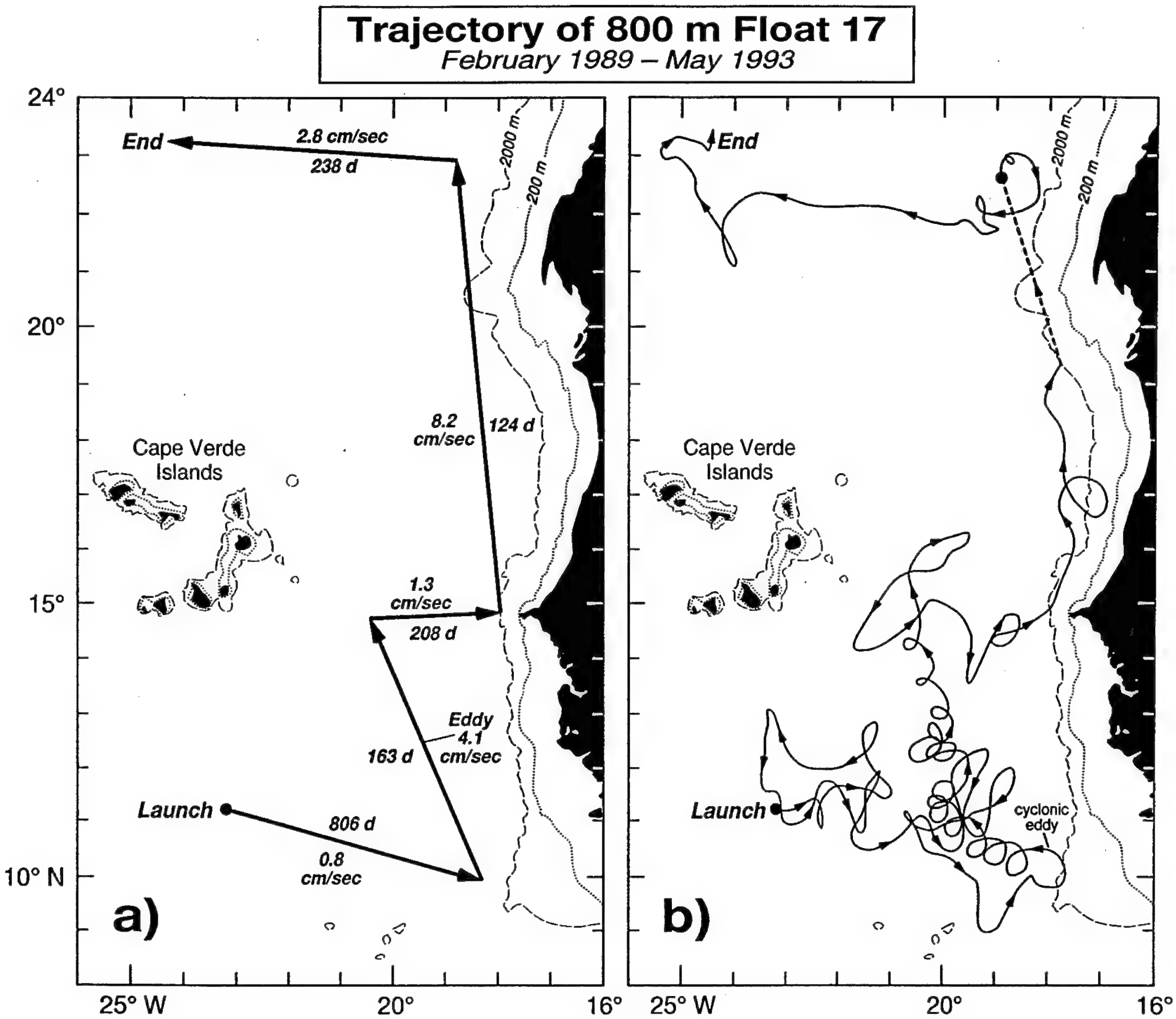

Figure 9: Trajectory of 800 m float 17 that drifted northward along the eastern boundary.

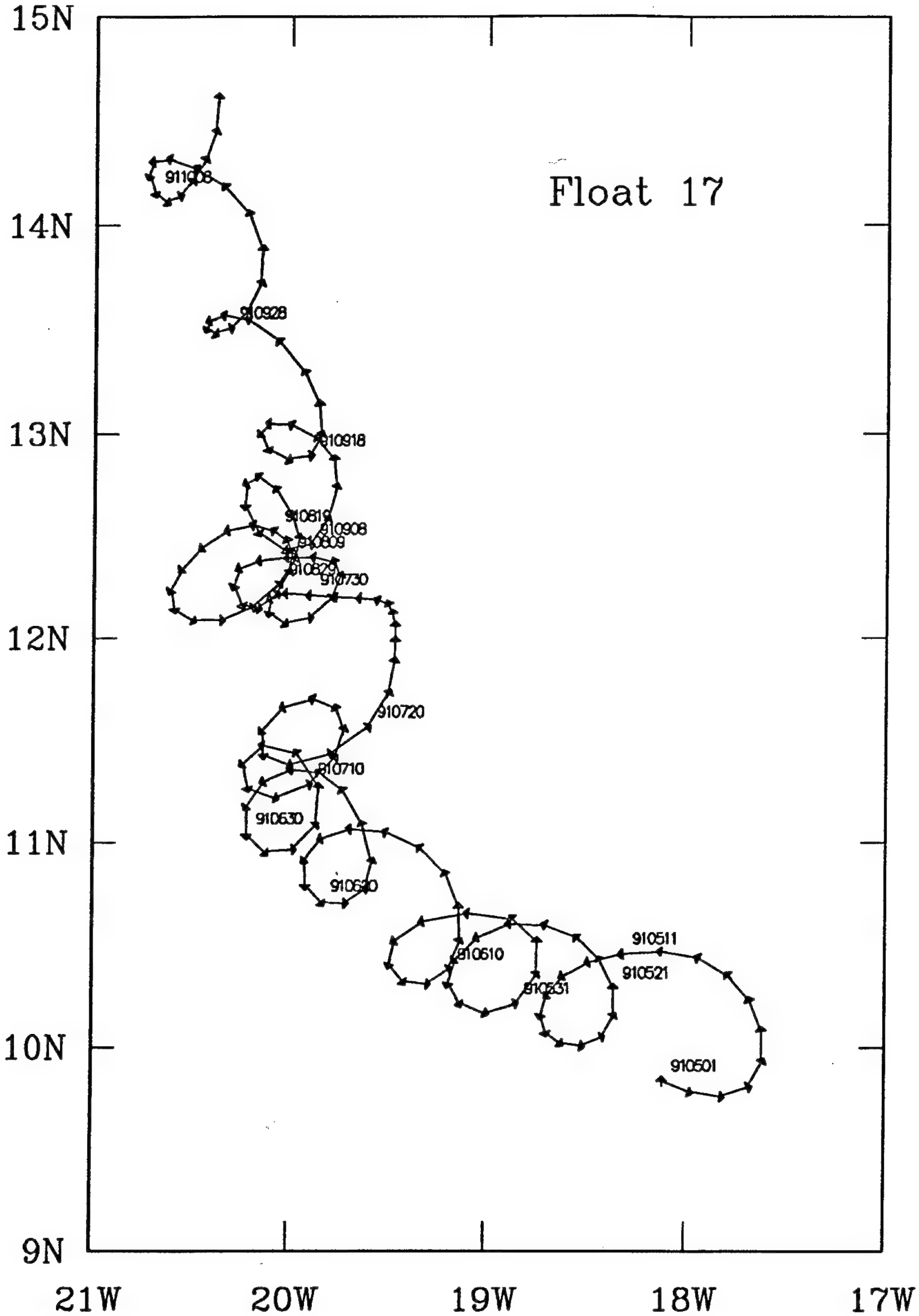

Figure 10: Trajectory of 800 m float 17 in a cyclonic eddy. The float made 14.3 loops over a 167 day period with a characteristic diameter of 50 km. The period of rotation was 12 days, the swirl speed was 18 cm/sec, and the eddy translated northwestward with a mean velocity of 4.1 cm/sec. Arrowheads are spaced at daily intervals.

Floats that were not near the boundaries tended to drift more zonally than meridionally. This is especially true for floats within the 6N–6S band near the equator. A second possible route for South Atlantic water to move northward is first northward along the western boundary and across the equator, then eastward toward the eastern boundary between 5–10N, then northward along the eastern boundary. Although no one float followed this whole path, portions of three float trajectories (17, 19, 20; see also 26) did follow this path. A third possible route northward would be for South Atlantic water to follow the eastern boundary across the equator, but there were no floats in this eastern region.

Equatorial floats tended to have long zonal trajectories with low frequency fluctuations (Figure 11). Float 26 went eastward 34° of longitude along 2N, reversed and returned westward 22°. Float 24 (at 1125 m) went 29° eastward along the equator. Float 16 drifted eastward 22° along 5S at an average speed of 27 cm/sec. At one point this float's eastward velocity exceeded 40 cm/sec. In general the fastest eastward (or westward) speeds were observed in the western part of the equatorial band.

b) 1800 m trajectories

A summary plot of the trajectories and displacement vectors of the 1800 m floats is given in Figure 12. The convoluted pattern of trajectories makes it difficult to see the details of the flow along the western boundary. To clarify this a schematic summary of float trajectories in the DWBC and near the equator was drawn (Figure 13). In it the high frequency small scale motions were subjectively removed keeping what is interpreted to be the dominant low frequency large scale motions. The continuity of the DWBC and its connection to zonal flow near the equator have been emphasized. For clarity, eastward going portions of equatorial trajectories are shown north of the equator and westward going portions south of the equator. The meridional structure shown in the figure is not meant to represent actual meridional structure of the currents which at least in the

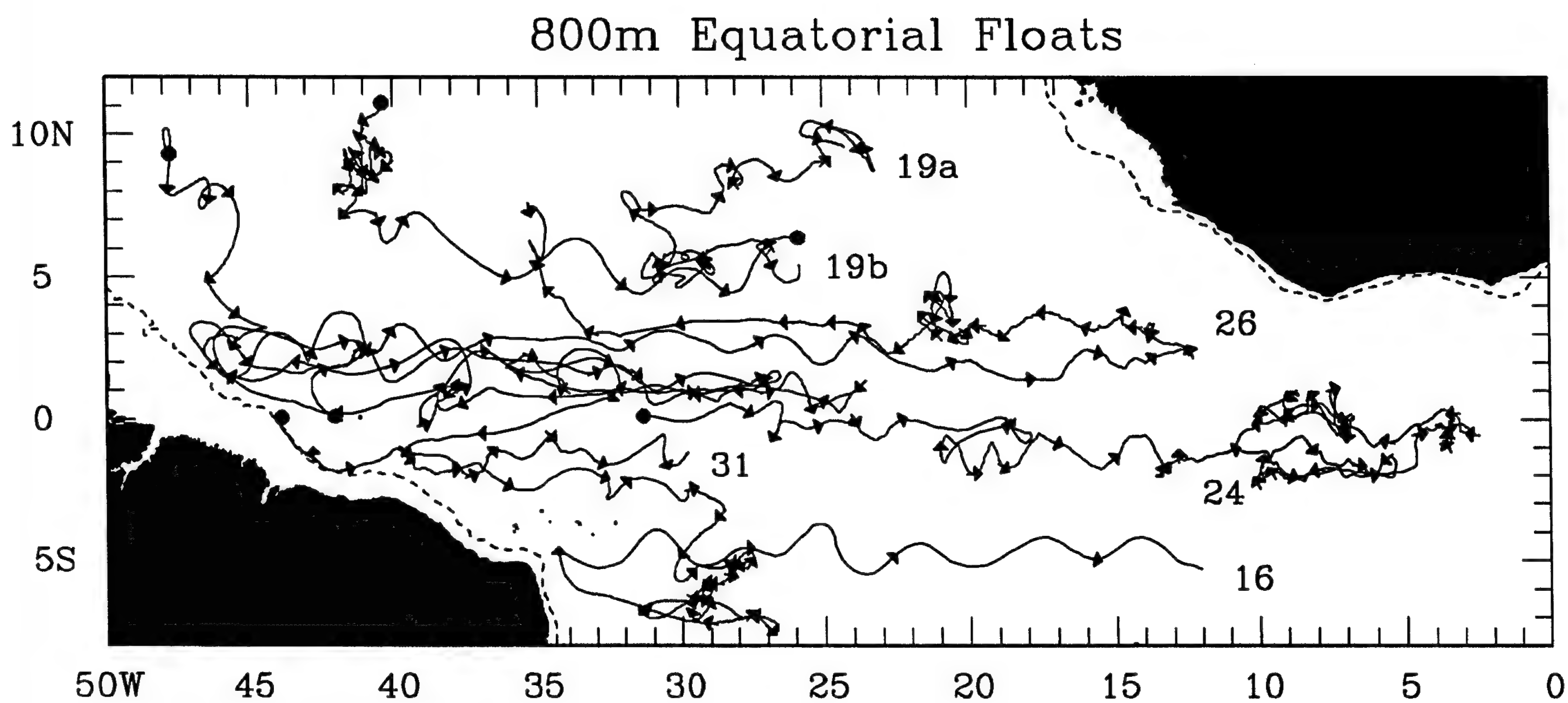

Figure 11a: Composite of five 800 m float trajectories along the equator from January 1989 to September 1992. Float 24 equilibrated to near 1125 m. Arrowheads are spaced at 30-day intervals.

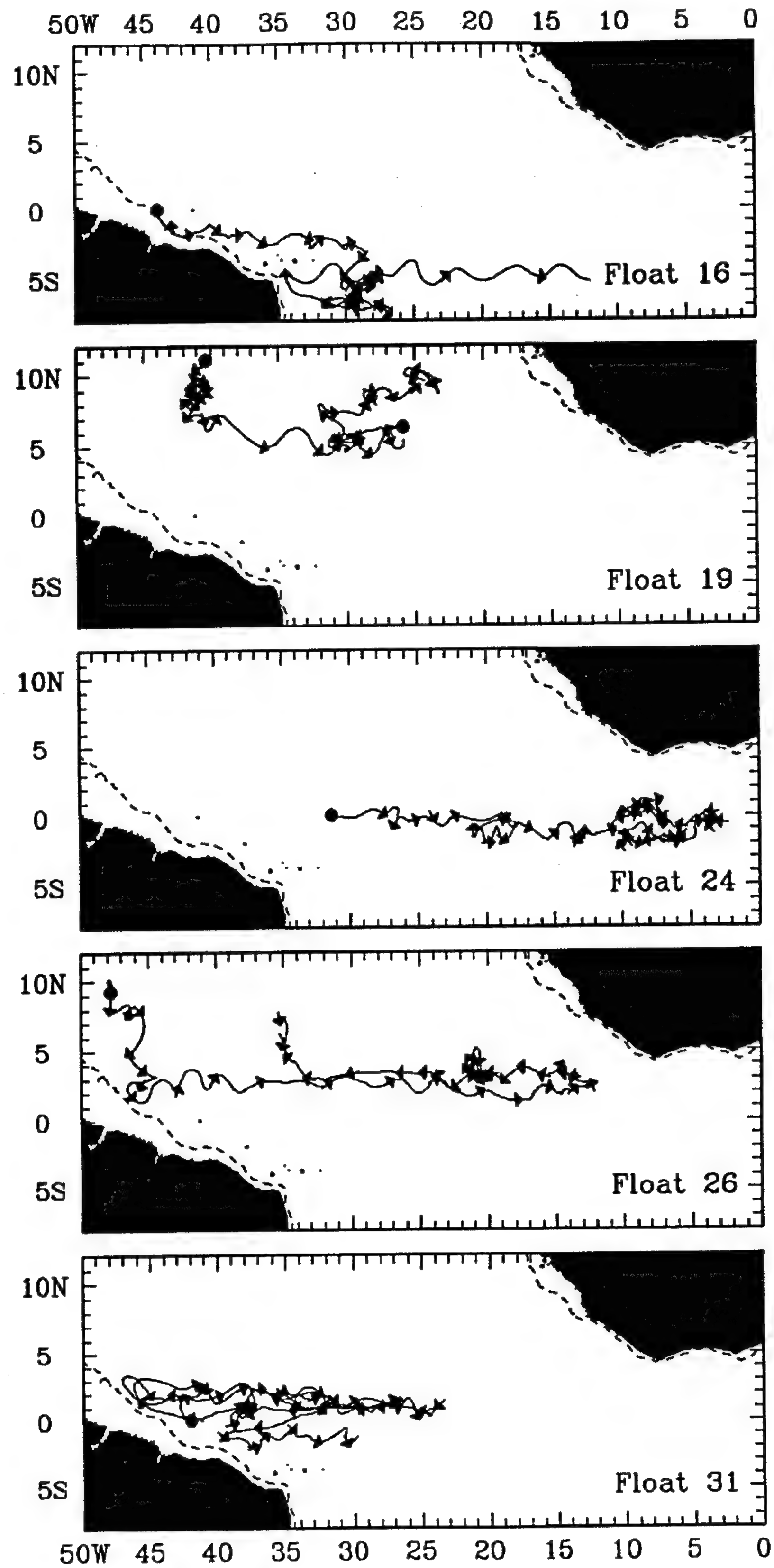

Figure 11b: Individual 800 m float trajectoreis along the equator from January 1989 to September 1992. Arrowheads are spaced at 30-day intervals.

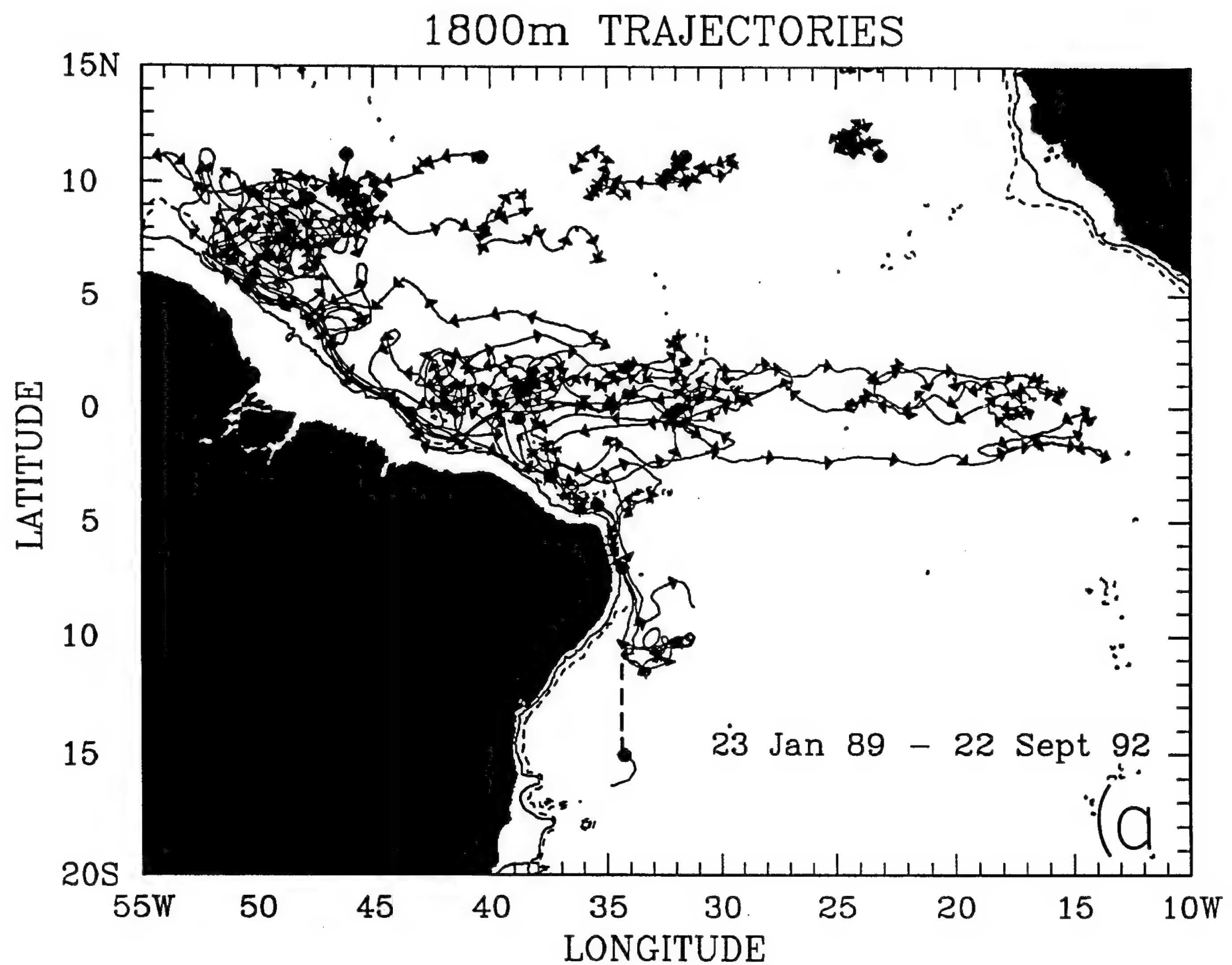

Figure 12a: Summary of 1800 m SOFAR float trajectories from January 1989 to September 1992. Arrowheads are spaced at intervals of 30 days along trajectories.

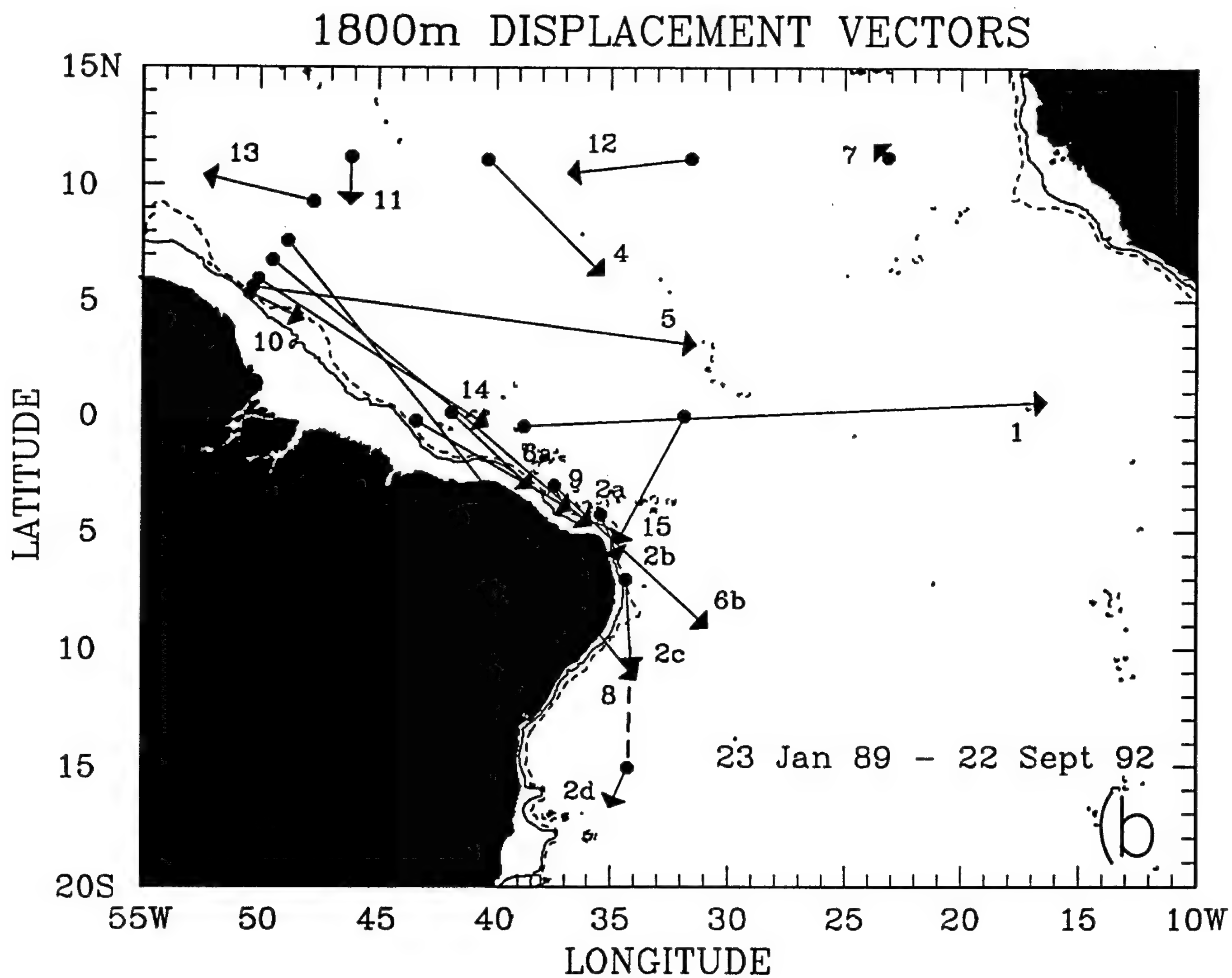

Figure 12b: Displacement vectors of 1800 m SOFAR float trajectories from January 1989 to September 1992. More than one vector are given for floats with gaps in their trajectories.

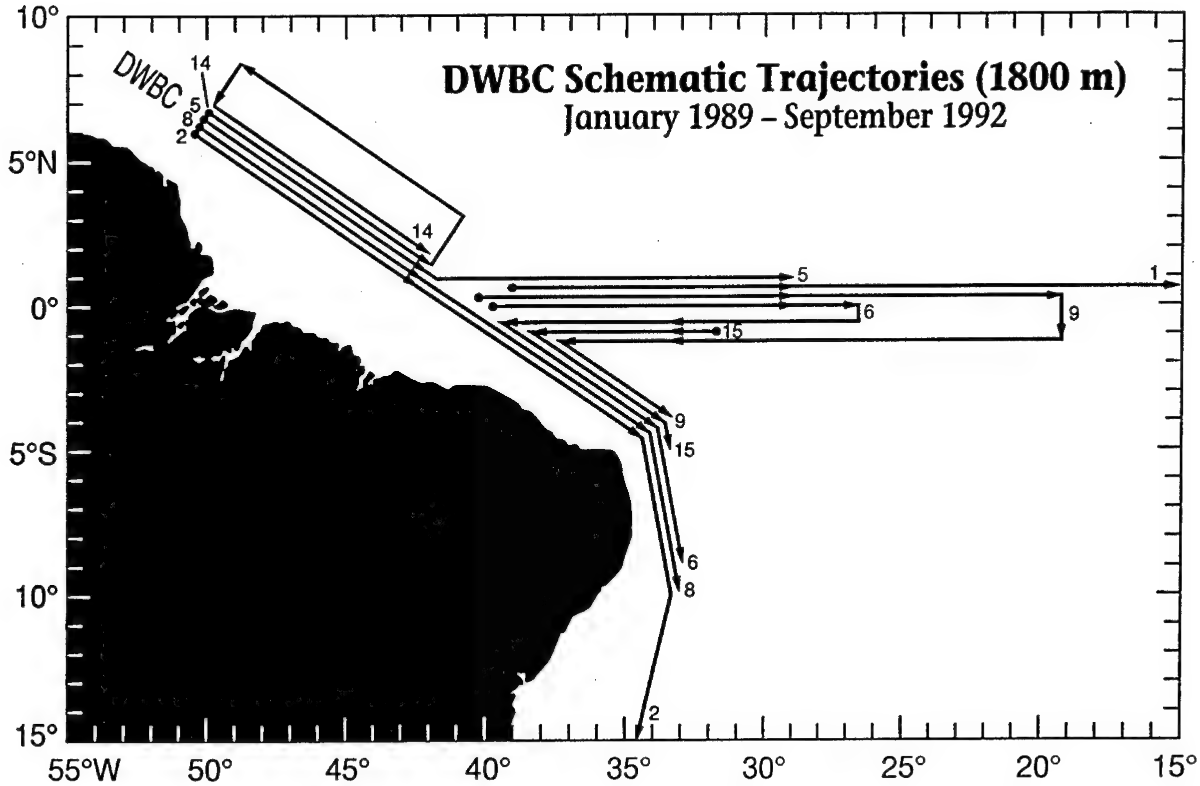

Figure 13: Schematic diagram of 1800 m trajectories in the DWBC near the equator. The trajectories were ordered in distance from the western boundary by how far south the floats travelled, starting with Float 2 that went the farthest south. The width of the DWBC as observed by floats is around 100 km.

mid-Atlantic, 10W–30W, looks like westward flow near the equator (1S–1N) and eastward flow centered near 2N and 2S. Detailed trajectories of four of the floats are given in Figure 14.

Five floats (2, 5, 8, 13, 14) were located in the DWBC near 7N. Two of these (2, 8) were launched offshore of the DWBC. They drifted westward into the DWBC then southward across the equator reaching 16S and 11S (Figure 15). Both of these made small scale recirculations near the equator. Float 5 drifted southward in the DWBC until reaching the equator where it went eastward ending up near 3N 32W. Float 14 drifted southward in the DWBC to the equator, recirculated northward to 9N and drifted southward in the DWBC a second time ending near 0N 40W. Float 13 is a very convoluted trajectory with portions in the DWBC and portions in recirculations some of which were located close to the western boundary. This trajectory which ended near 10N 52W was judged too complicated to include in the schematic.

Four floats (1, 6, 9, 15) were launched near the equator in the western Atlantic. Float 1 went eastward along 2S ending up near 0N 18W (Figure 14). Float 6 went eastward along 2N to 27W, returned westward along 0N–1N, entered the DWBC and went southward past 9S (Figure 15). Float 9 launched in the DWBC on the equator drifted eastward to 19W, back westward, and then southward along the western boundary to 4S. Float 15 drifted slowly westward along the equator, then southward along the western boundary, ending at 5S.

There is good evidence that most of the DWBC water crosses the equator in the west either directly (floats 2 and 8) or indirectly with an eastward diversion along the equator. Floats 1, 5 and 9 show a direct connection between flow in the DWBC north of the equator and flow along the equator. Floats 6, 9 and 15 show that water along the equator can eventually return to the western boundary and go south in the DWBC. Taken together the above two groups of floats imply that DWBC water can go eastward along the equator but that it probably eventually

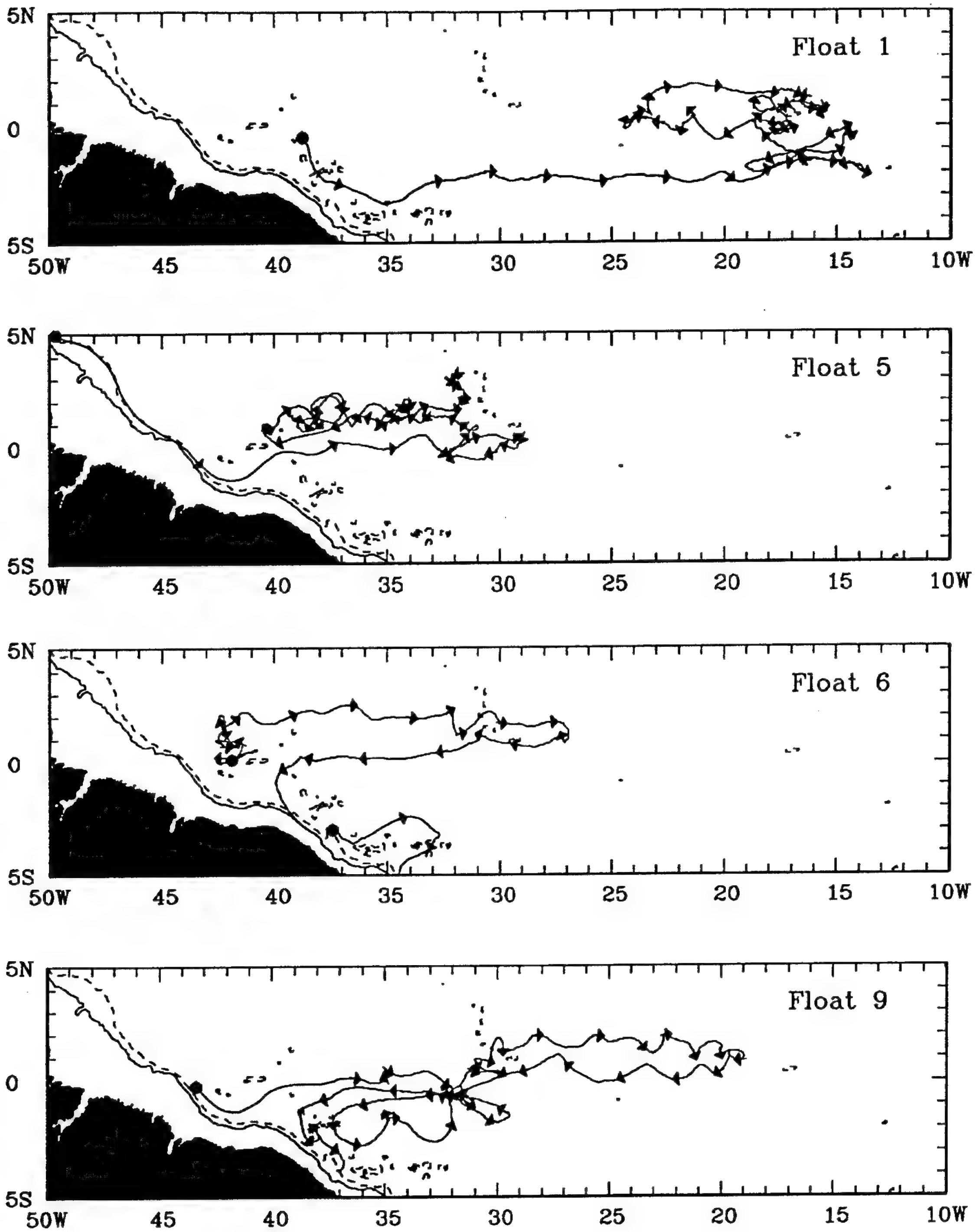

Figure 14: Individual 1800 m float trajectories near the equator. The dashed contour is 2000 m. Arrowheads are spaced at 30-day intervals.

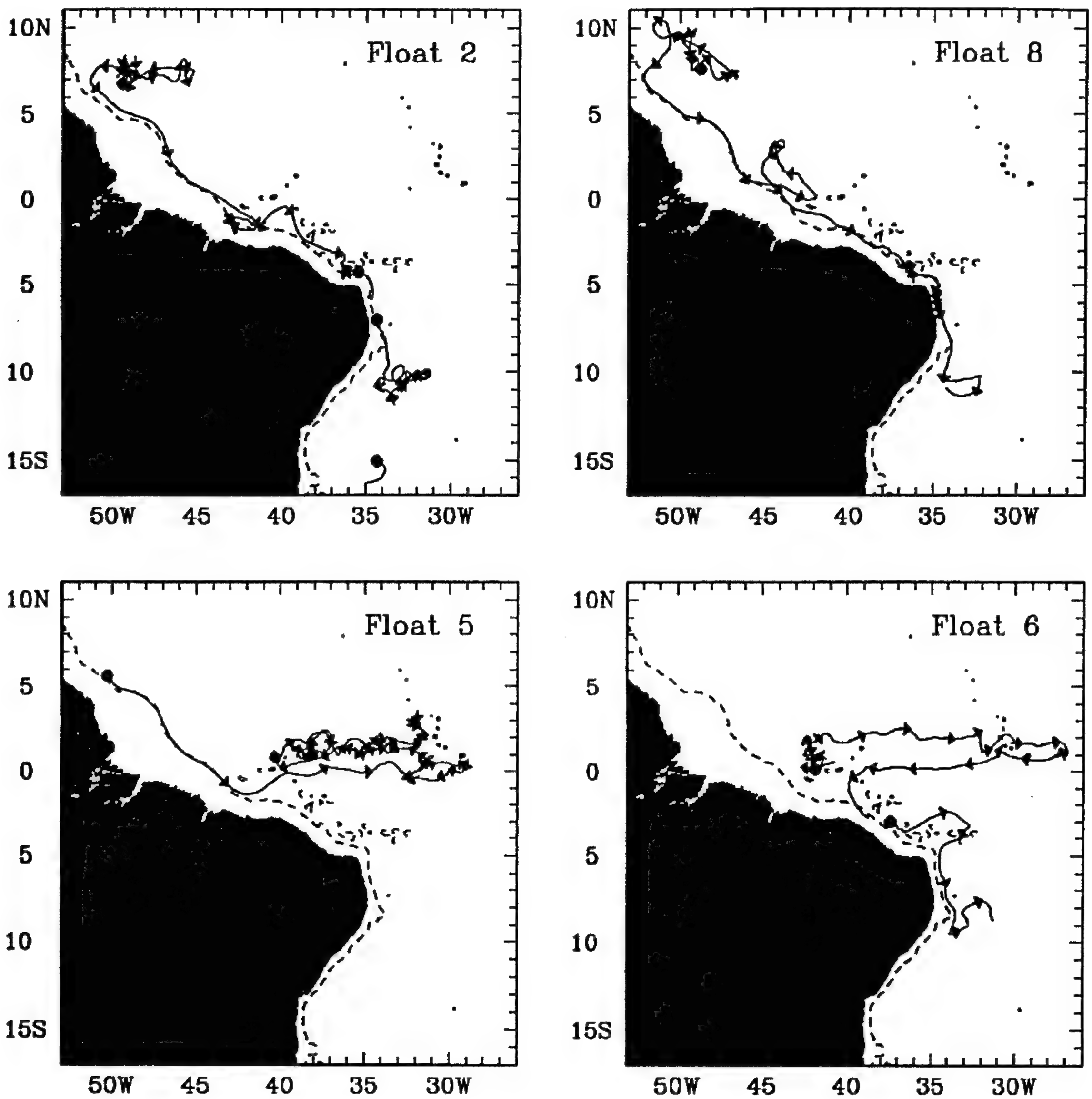

Figure 15: Individual 1800 m float trajectories along the western boundary. The dashed contour is 2000 m.

returns westward and continues southward in the DWBC. There is no evidence for continuous eastward flow along the equator to the eastern boundary or for meridional flow outside the DWBC. A possible explanation for why floats 1 and 5 never returned westward very far is that by the latter part of the experiment they had descended below 2200 m into weaker zonal currents as observed on an equatorial velocity profile (see Ponte *et al.*, 1990, or Richardson *et al.*, 1992).

Floats 2 and 8 took 14 months and 12 months to go from 7N to 10S with mean along-boundary velocities of 8.1 cm/sec and 8.6 cm/sec respectively. Values for float 8 were adjusted for the 4.3 months it was aground and slowly (1.5 cm/sec) dragging along the sea floor. The mean along-boundary velocity of float 14 including its two passes down the boundary from roughly 6N to the equator and its recirculation was 1.1 cm/sec. The mean along-boundary velocity of floats 6 and 9 from their launch locations near the equator to 9S (float 6) and 4S (float 9) was 2.5 cm/sec and 0.7 cm/sec respectively. The value for float 6 was adjusted for the 19 months it was aground and stuck near 3S.

In summary, at times DWBC water flows directly southward across the equator with a mean velocity of 8–9 cm/sec averaged over long distances (~2800 km). Some DWBC water is recirculated which reduces its mean along-boundary velocity substantially. At other times DWBC water is diverted eastward near the equator for long times — 1.7 years for float 6, 3.3 years for float 9 — which also can reduce the mean along-boundary velocity to 1–2 cm/sec. These mean velocities are considerably smaller than instantaneous along-boundary float velocities which are often above 25 cm/sec and occasionally exceed 50 cm/sec.

All three DWBC floats that went the farthest south diverged away from the western boundary near 8.5S where the orientation of the western boundary becomes more southwestward. Float 2 left the boundary and became trapped in a cyclonic eddy near 10S 32W for 170 days (Figure 16). The eddy did not move far. After leaving the eddy float 2 continued southward to 16S although tracking was

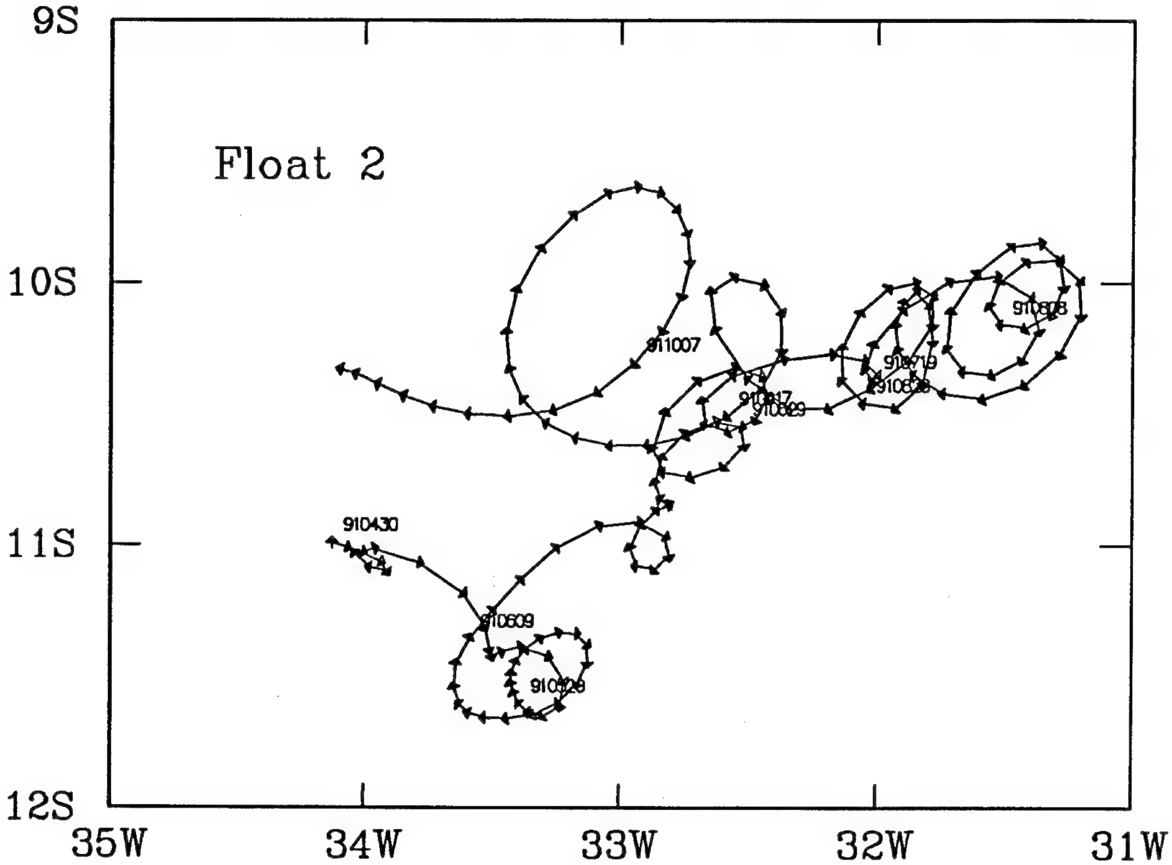

Figure 16: Trajectory of 1800 m float 2 while it was looping in a cyclonic eddy from April to October 1991. The float looped 15.5 times with a period of 11 days and a swirl velocity of 16 cm/sec. Arrowheads are spaced at daily intervals.

intermittent because topography blocked the acoustic signals. Float 8 drifted south to 10.5S and made a partial cyclonic loop around the eddy in which float 2 was trapped. Float 6 went south to 9.5S then turned and drifted eastward.

c) 3300 m trajectories

A summary plot of the trajectories and displacement vectors is given in Figure 17. The most remarkable aspect of these is the lack of any consistent indication of a DWBC at this level (as discussed by Richardson and Schmitz, 1993). One float (30) does appear to drift southward along the boundary and eastward near 10S, similar to some 1800 m floats. Because this trajectory seems rather anomalous compared to the other 3300 m trajectories and because it passes over some relatively shallow (< 2000 m) topography, we think this float could have equilibrated at a shallower depth than 3300 m.

Acknowledgements

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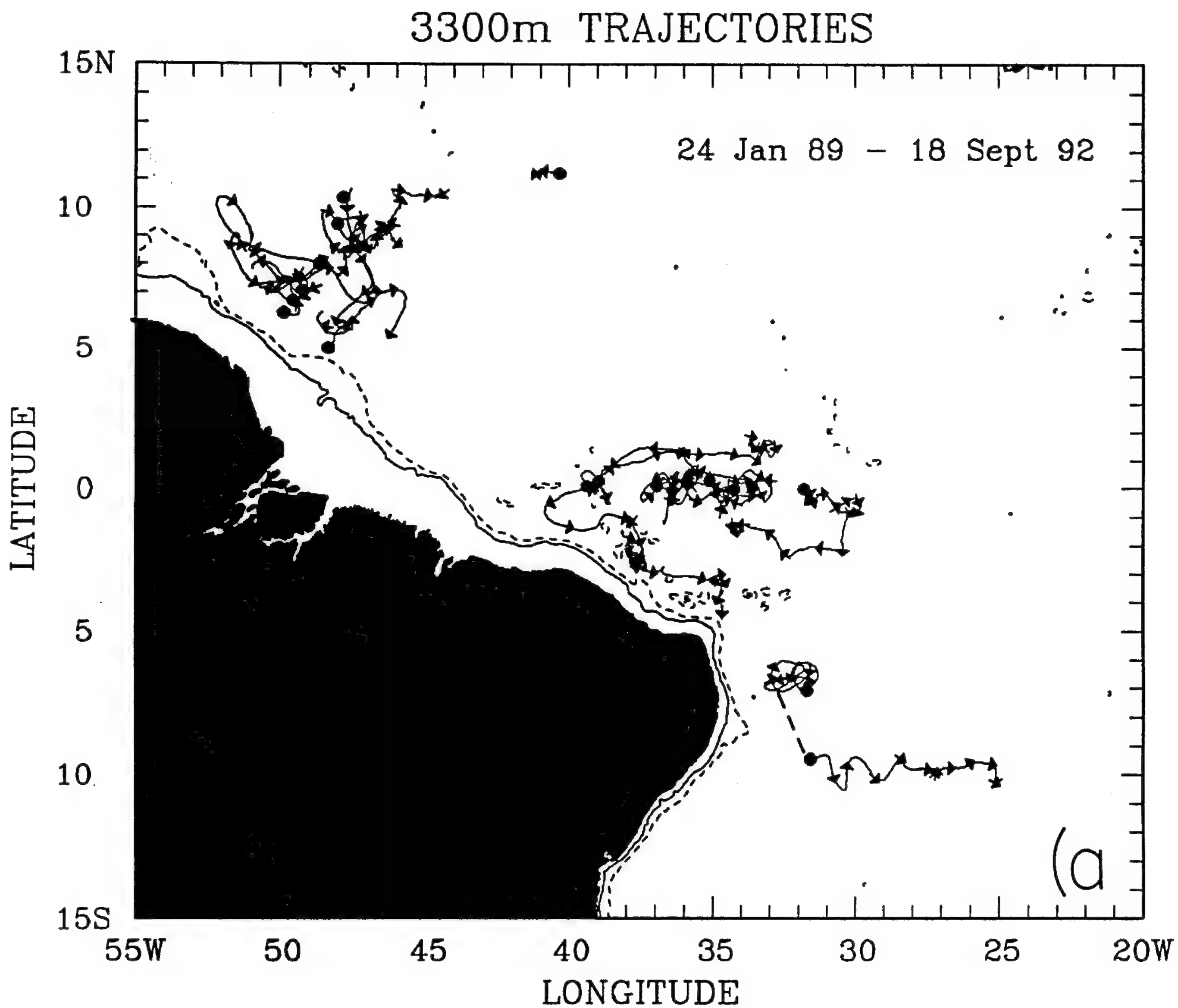

Figure 17a: Summary of 3300 m float trajectories from January 1989—September 1992. Arrowheads are spaced at 30-day intervals.

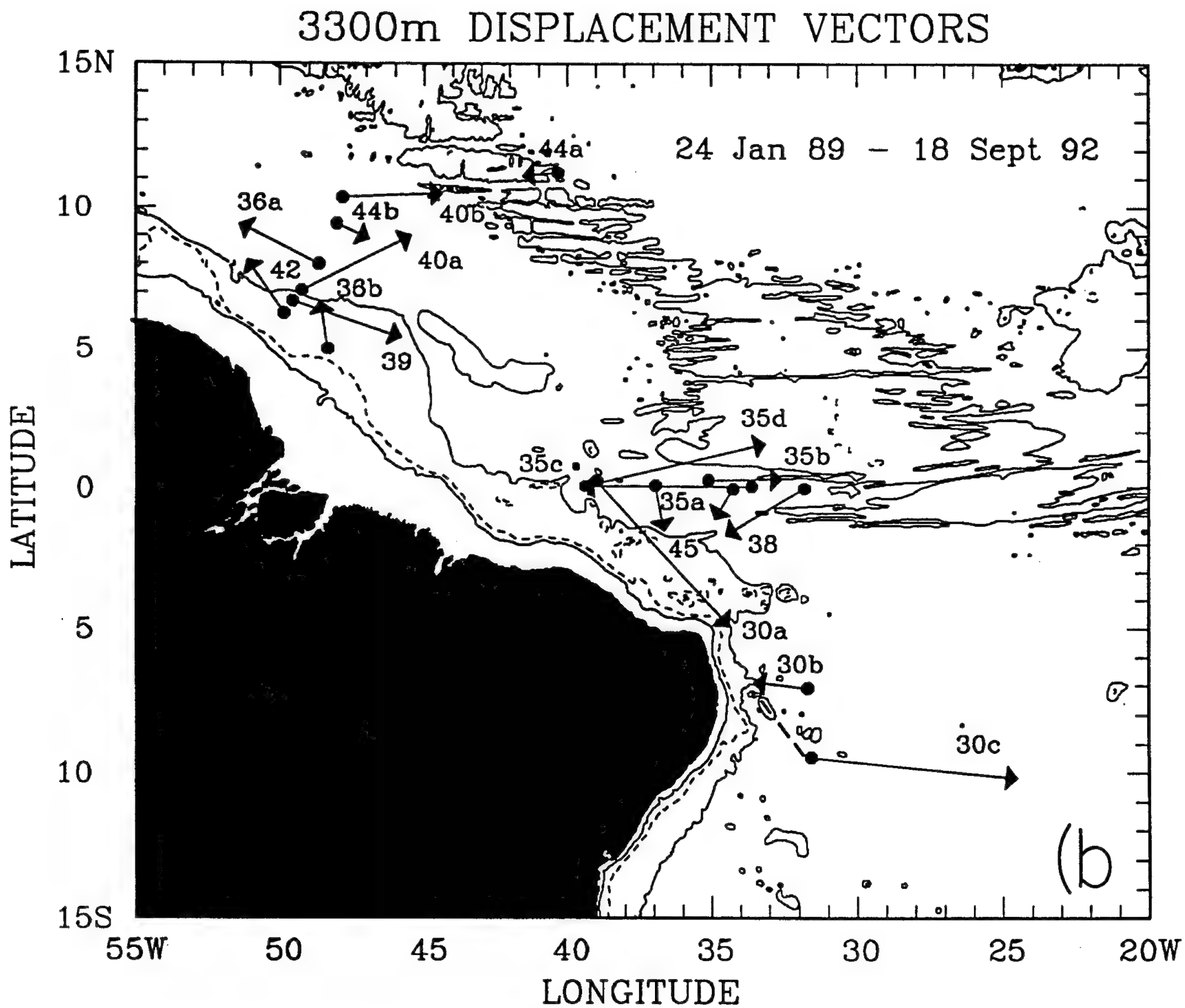

Figure 17b: Displacement vectors of the 3300 m floats from January 1989—September 1992.

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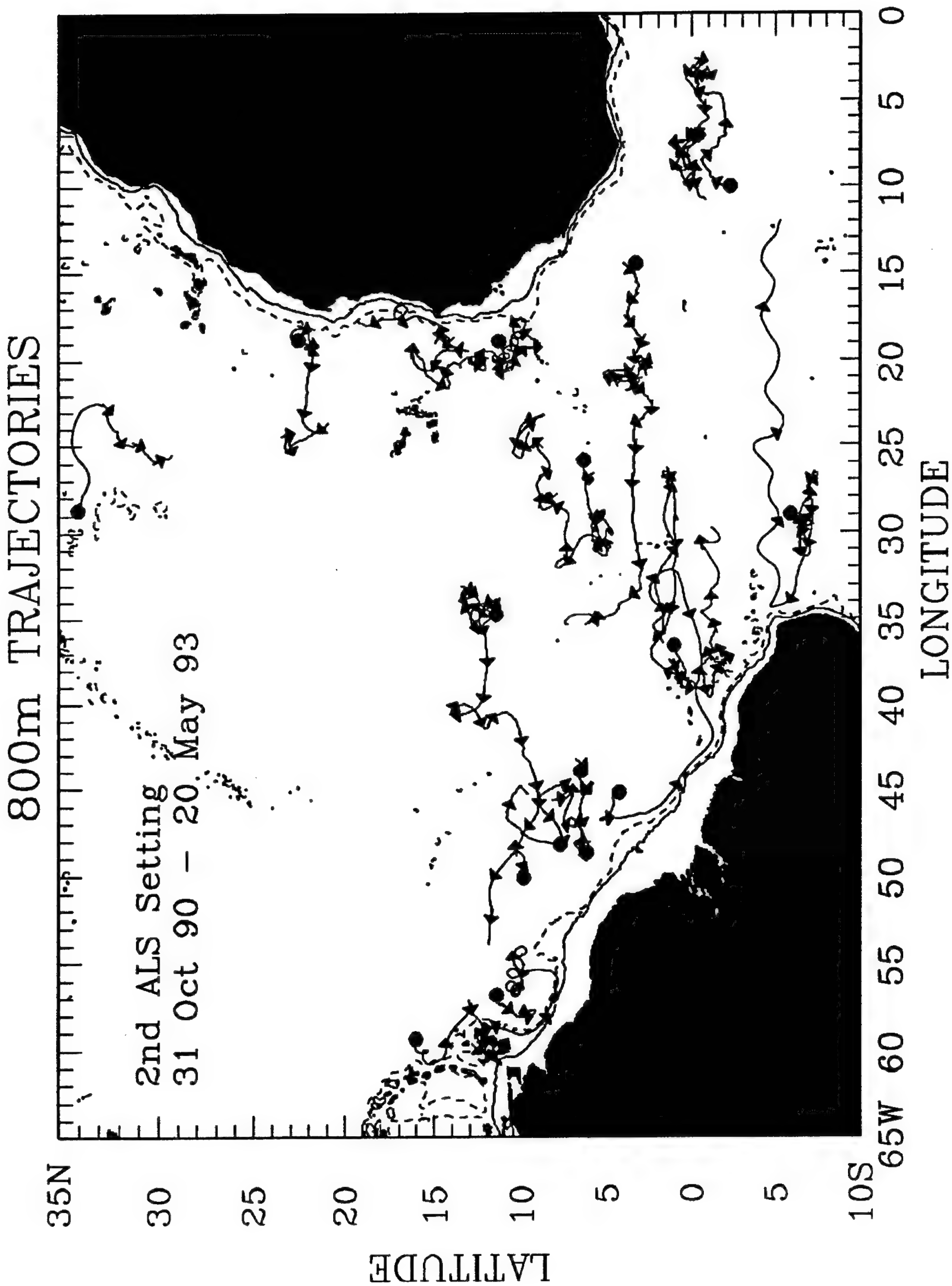
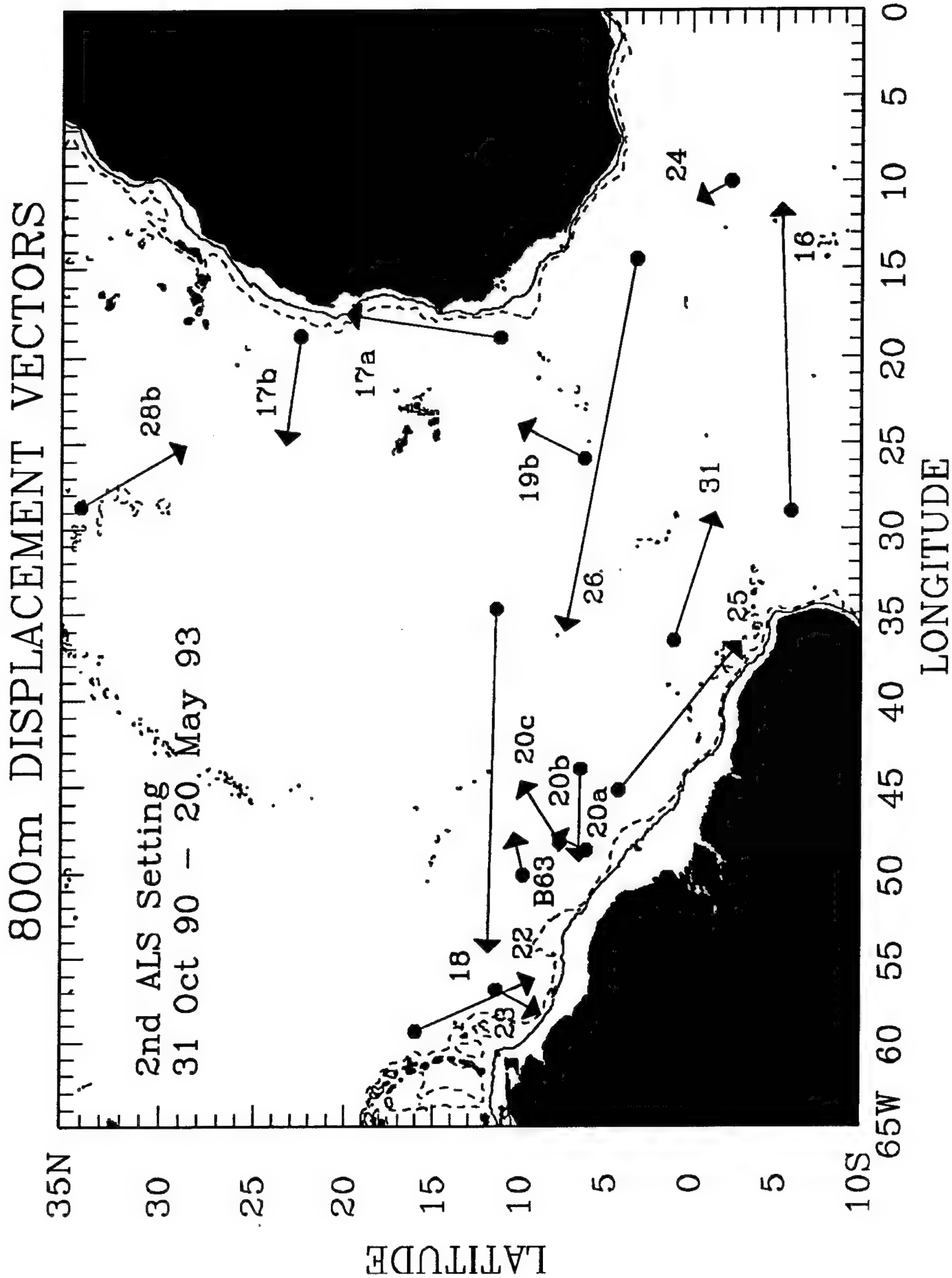
Appendix A: Summary Composites of Trajectories

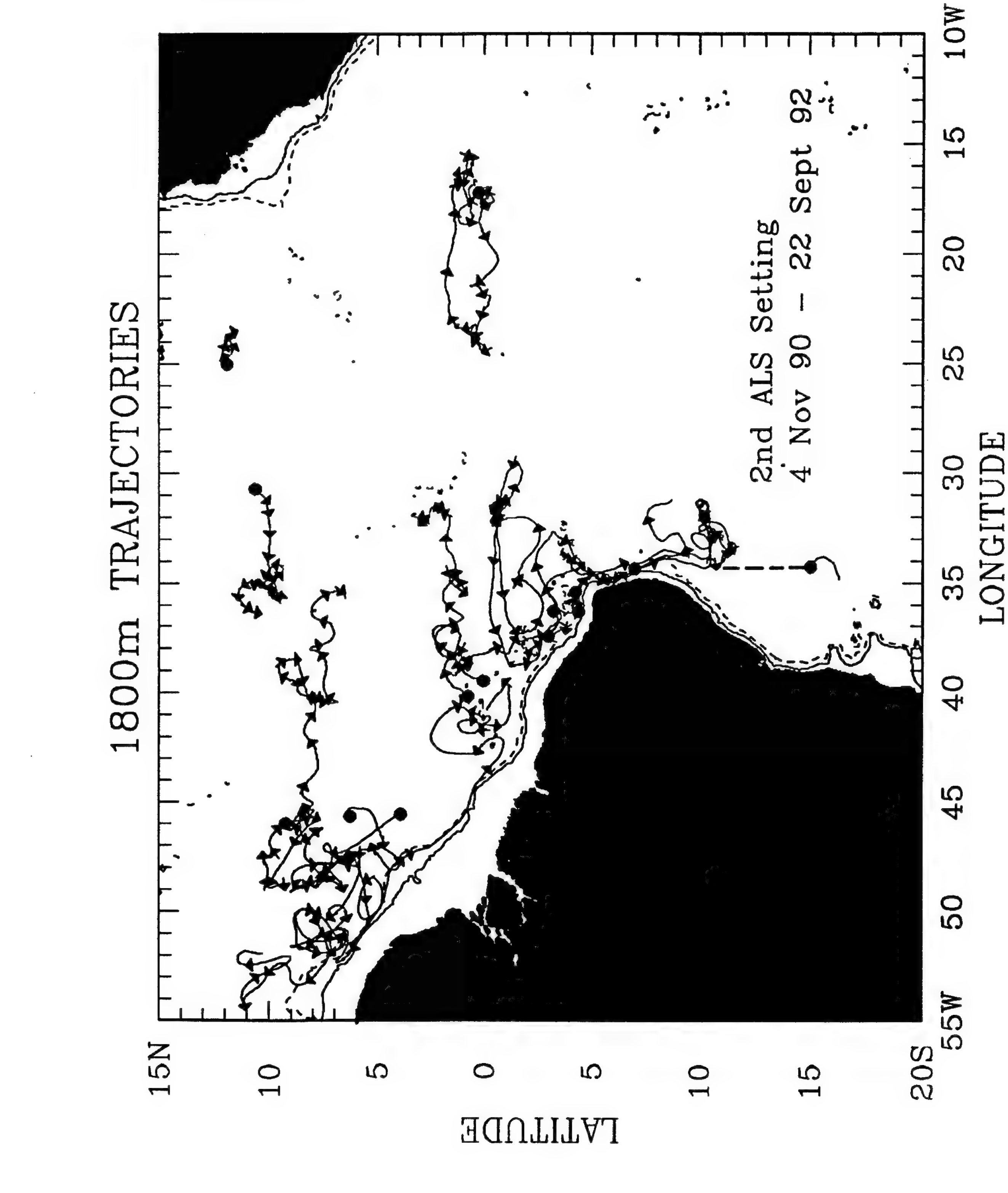
The following figures include:

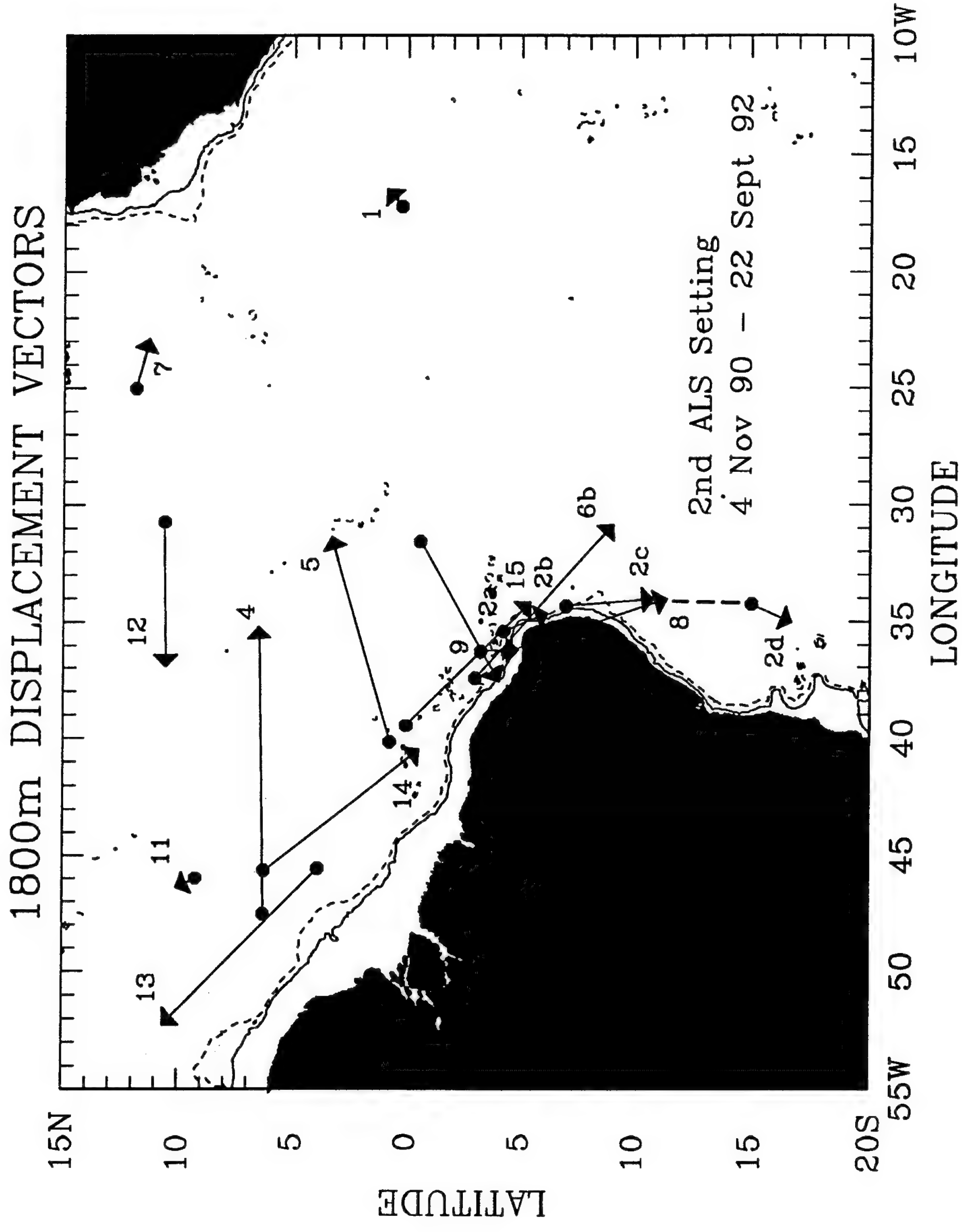
1. Trajectories and displacement vectors at each depth for the second ALS setting, October 1990–September 1992 (6 figures);
2. Summaries of eastbound and westbound floats near the equator at 800 m (floats 16, 19, 24, 26, 31, 34) and 1800 m (floats 1, 5, 6, 9) for the whole experiment (2 figures);
3. Portions of trajectories during which the floats drifted faster than 20 cm/sec (2 figures);
4. Time–latitude and time–longitude plots of near equatorial floats (4 figures);
5. Yearly composites of all floats at each depth (6 figures); and
6. Three-month composites of all floats at each depth (24 figures).

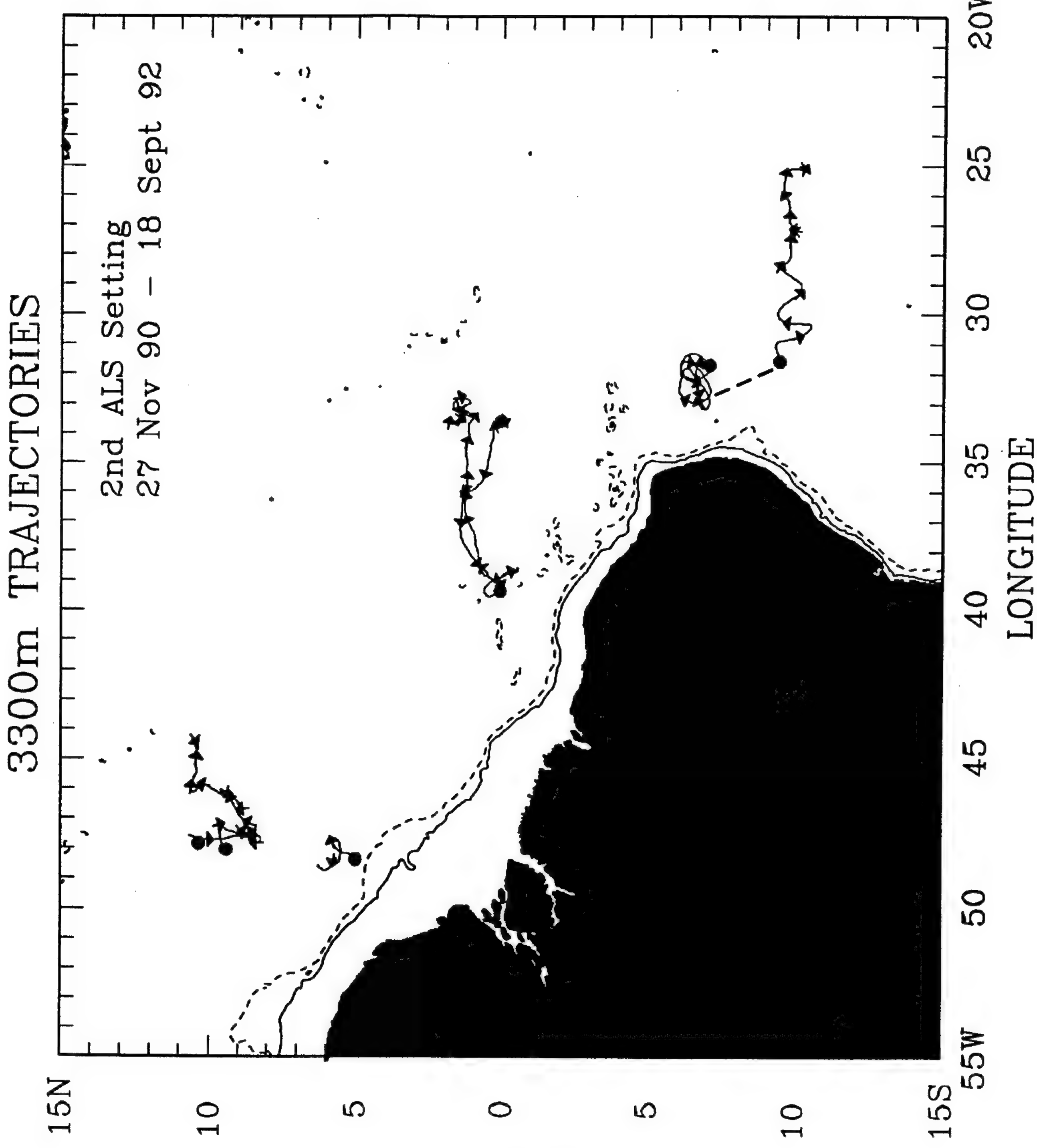

800m TRAJECTORIES
2nd ALS Setting
31 Oct 90 - 20 May 93
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

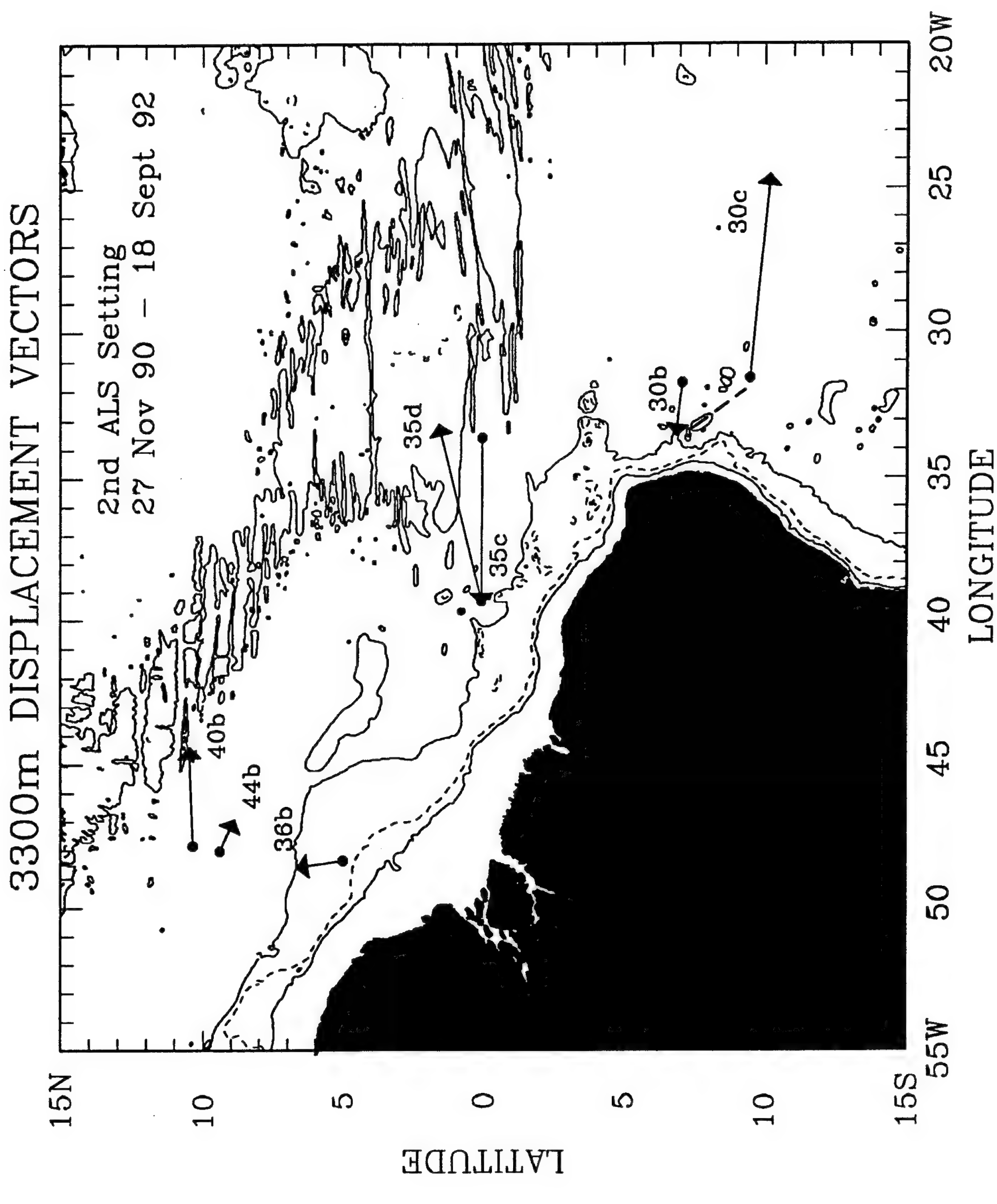


800m DISPLACEMENT VECTORS
2nd ALS Setting
31 Oct 90 – 20 May 93
LONGITUDE
LATITUDE
28b
17b
17a
19b
26
31
25
24
16
18
22
23
B63
20a
20b
20c


1800m TRAJECTORIES
2nd ALS Setting
4 Nov 90 - 22 Sept 92
LATITUDE
LONGITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

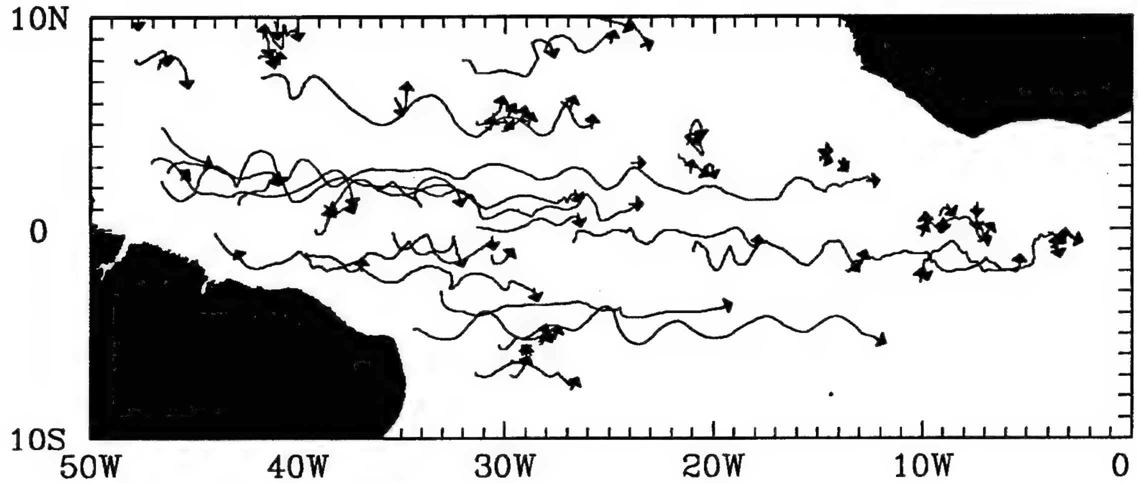

1800m DISPLACEMENT VECTORS
2nd ALS Setting
4 Nov 90 – 22 Sept 92
LATITUDE
LONGITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W
1
2a
2b
2c
2d
4
5
6b
7
8
9
11
12
13
14
15


3300m TRAJECTORIES
2nd ALS Setting
27 Nov 90 — 18 Sept 92
LATITUDE
LONGITUDE
15N
10
5
0
5
10
15S
55W
50
45
40
35
30
25
20W

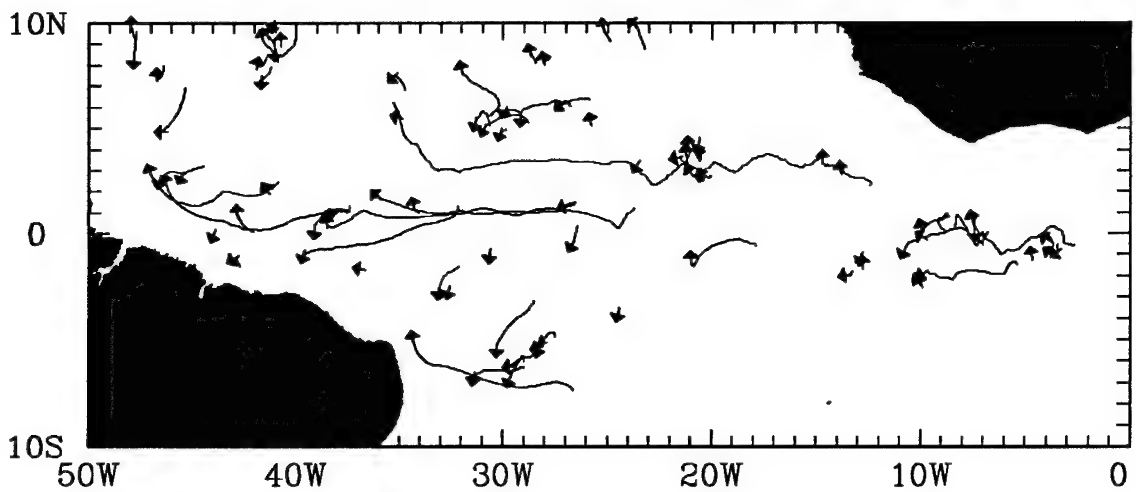


3300m DISPLACEMENT VECTORS
2nd ALS Setting
27 Nov 90 – 18 Sept 92
LATITUDE
15N
10
5
0
5
10
15S
LONGITUDE
55W
50
45
40
35
30
25
20W
40b
44b
36b
35d
35c
30b
30c

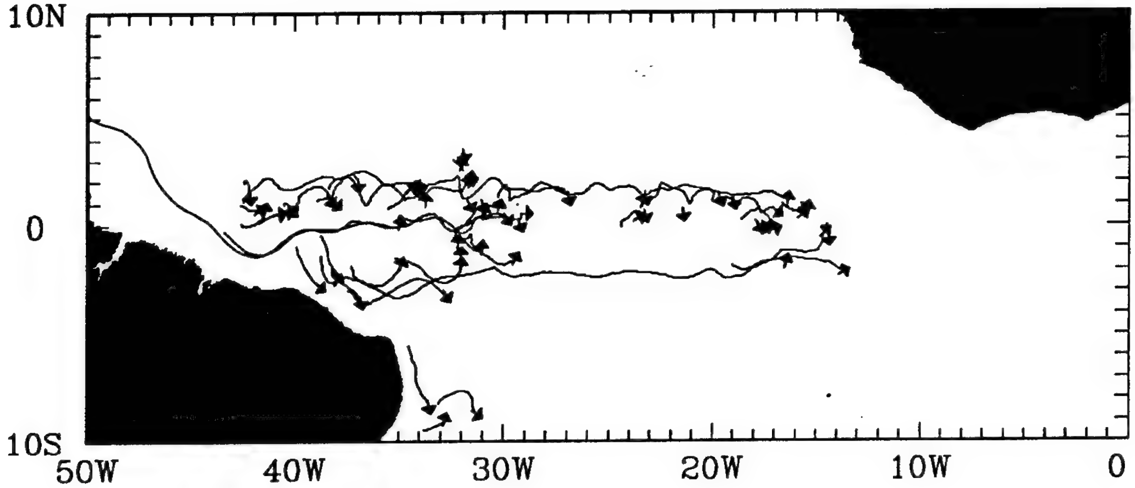
800m Eastward Drifting Floats



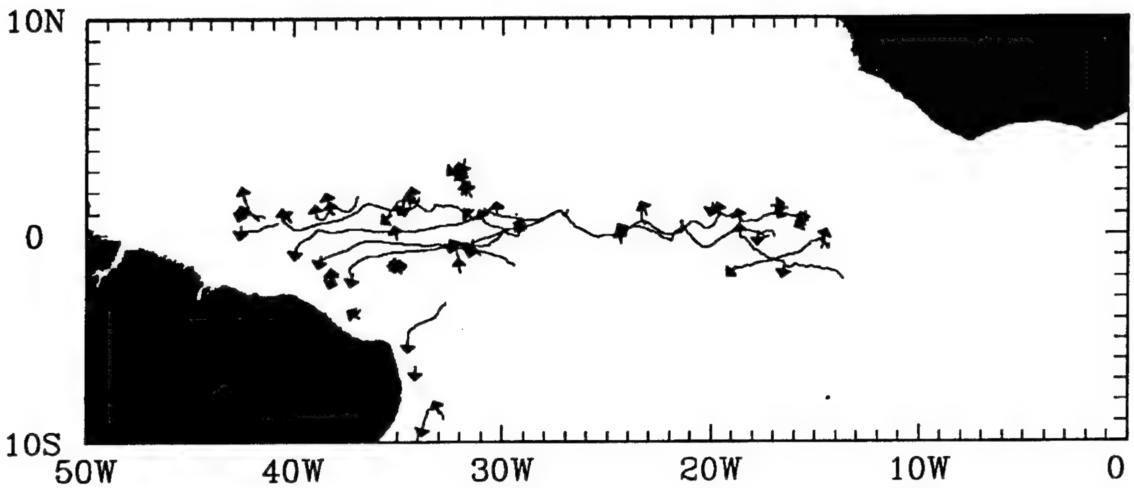
800m Westward Drifting Floats



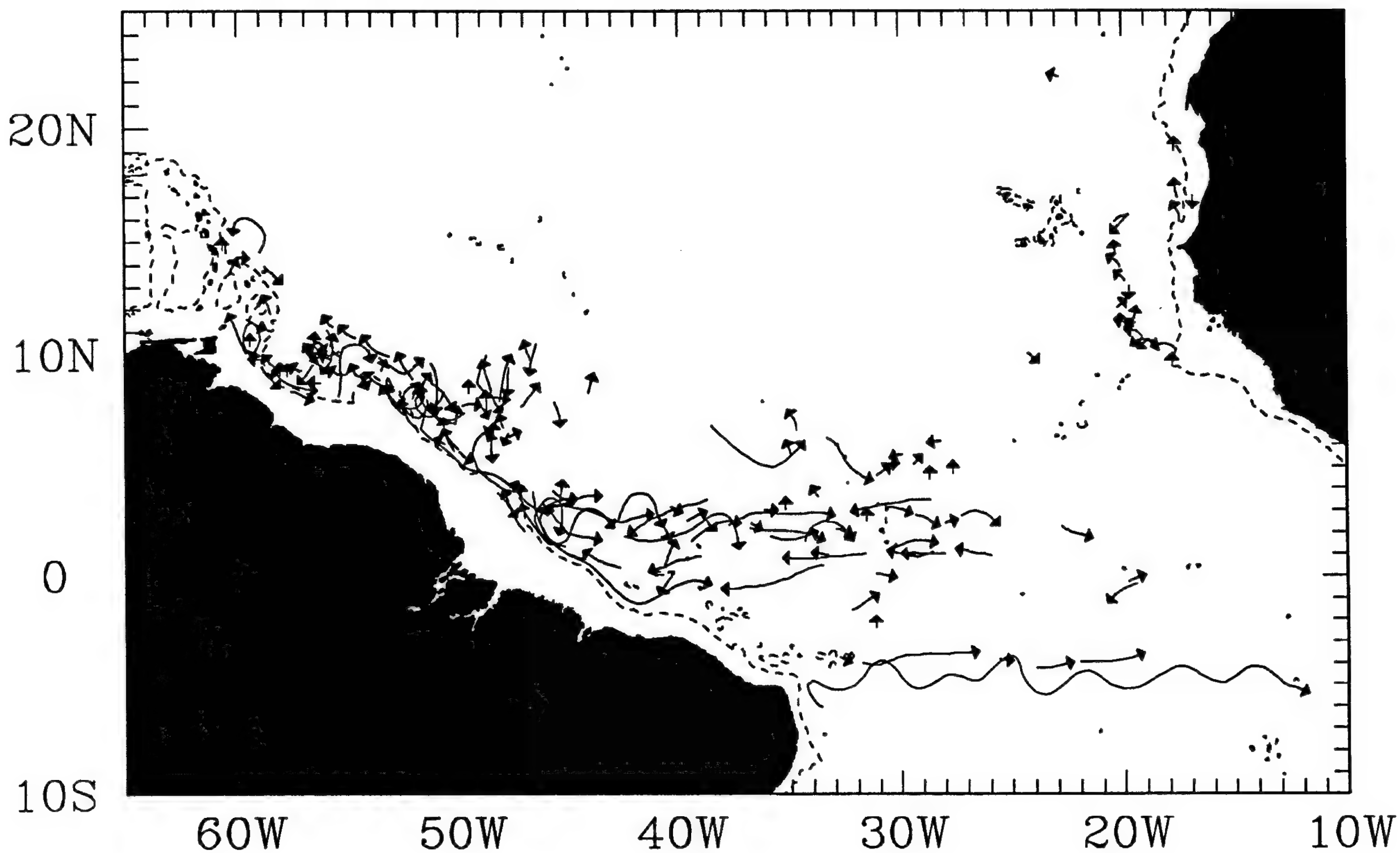
1800m Eastward Drifting Floats

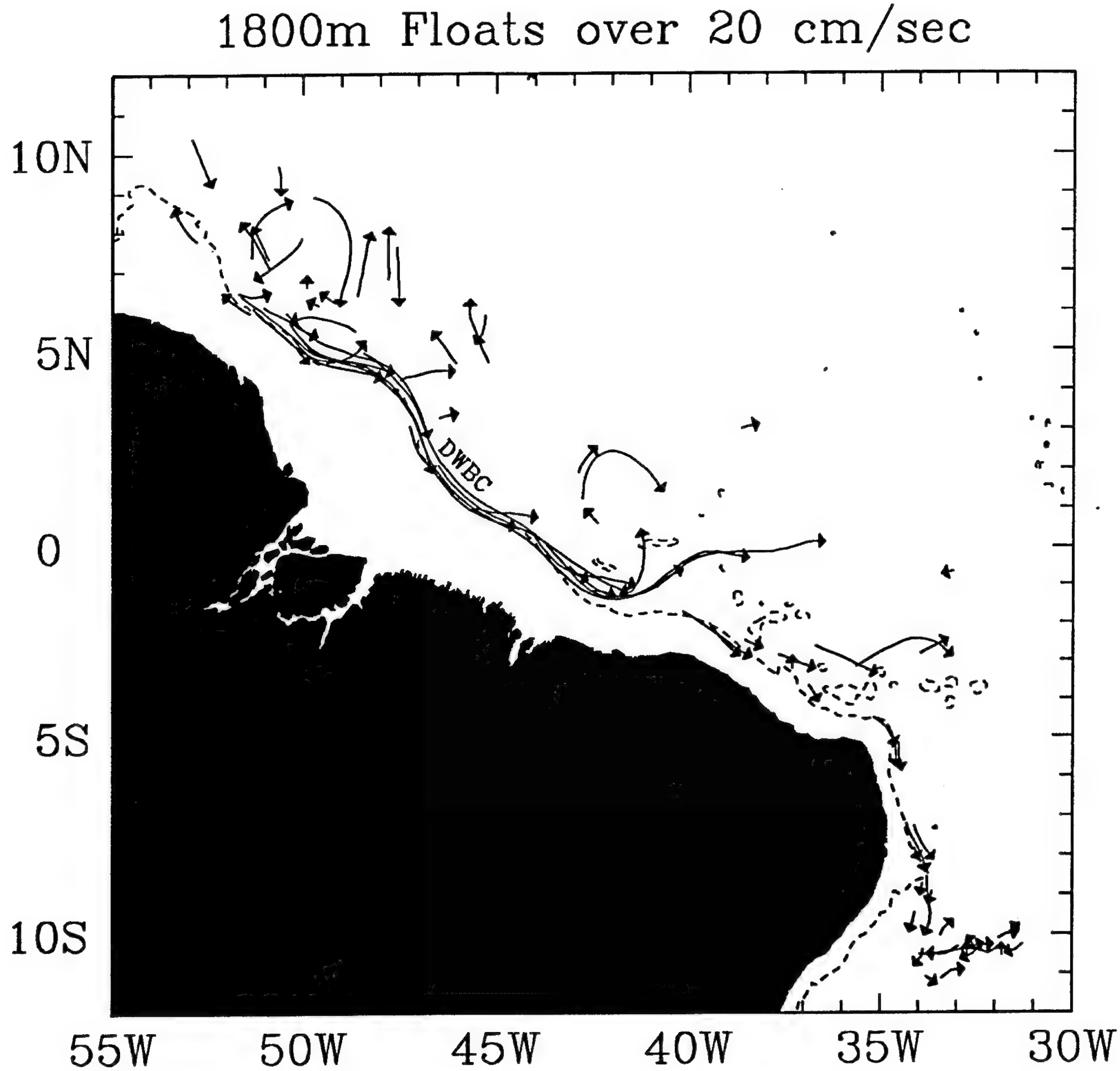


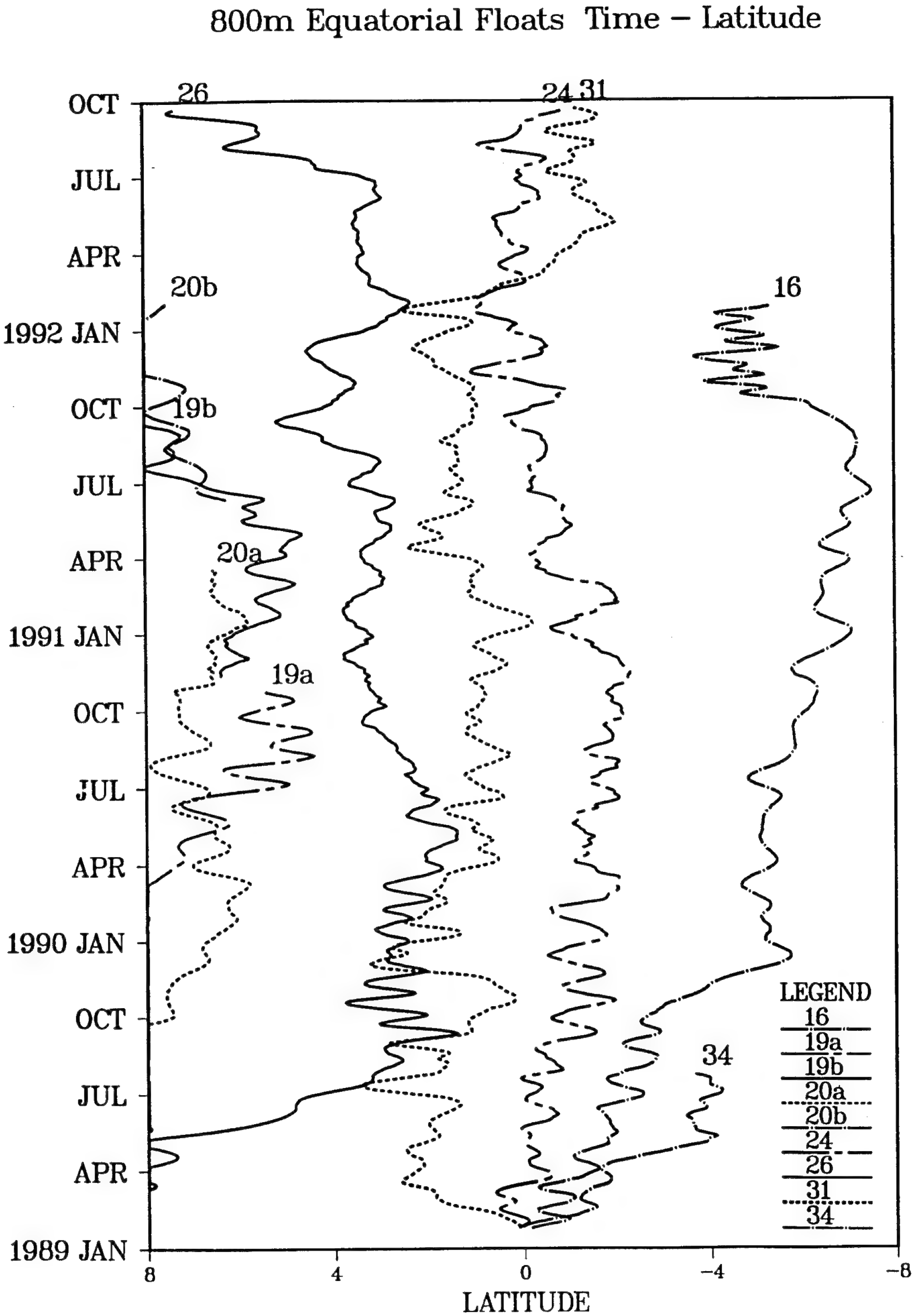
1800m Westward Drifting Floats



800m Floats over 20 cm/sec

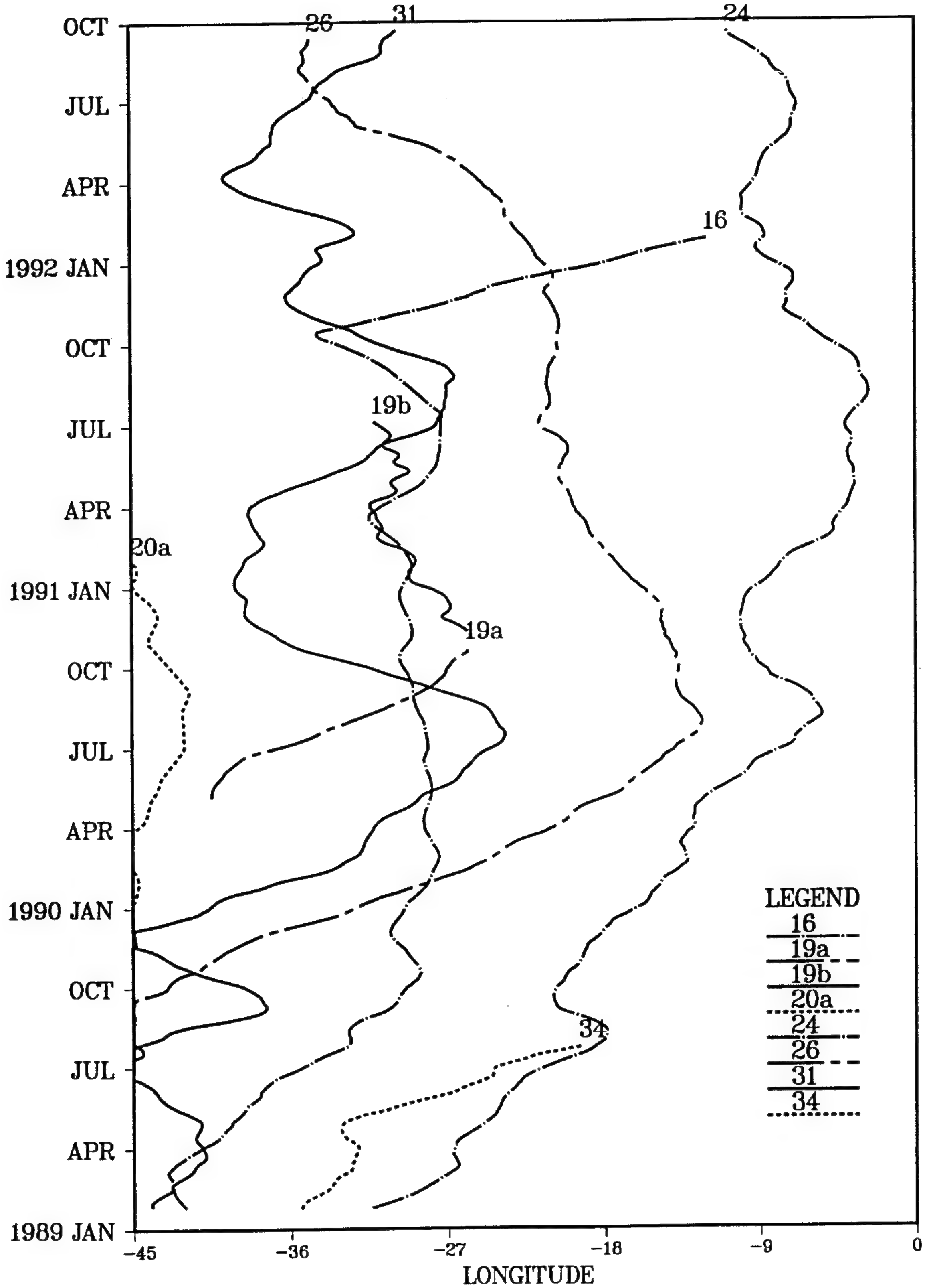


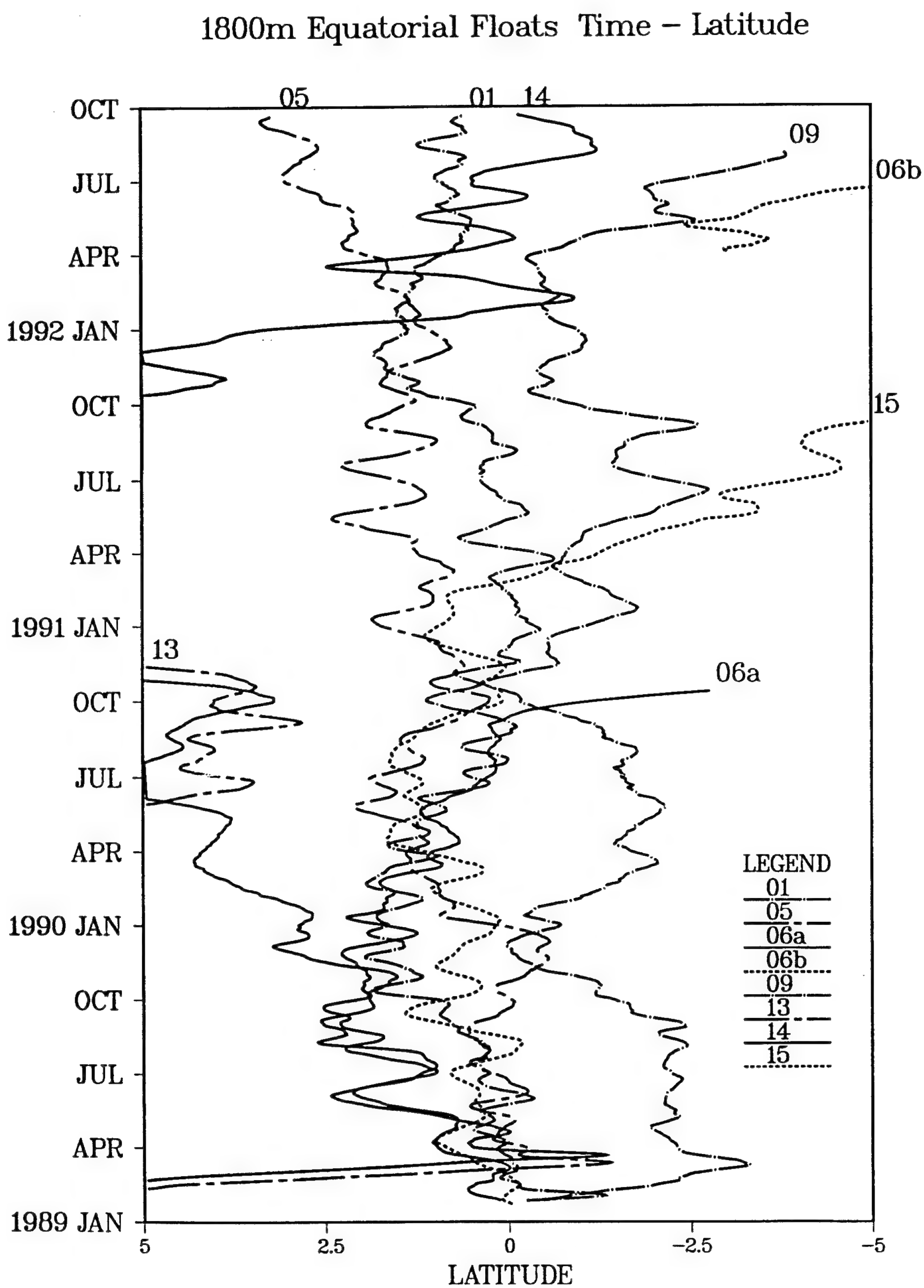

1800m Floats over 20 cm/sec
10N
5N
0
5S
10S
55W
50W
45W
40W
35W
30W
DWBC



800m Equatorial Floats Time – Latitude
OCT
JUL
APR
1992 JAN
OCT
JUL
APR
1991 JAN
OCT
JUL
APR
1990 JAN
OCT
JUL
APR
1989 JAN
8
4
0
−4
−8
LATITUDE
26
24
31
20b
16
19b
20a
19a
34
LEGEND
16
19a
19b
20a
20b
24
26
31
34

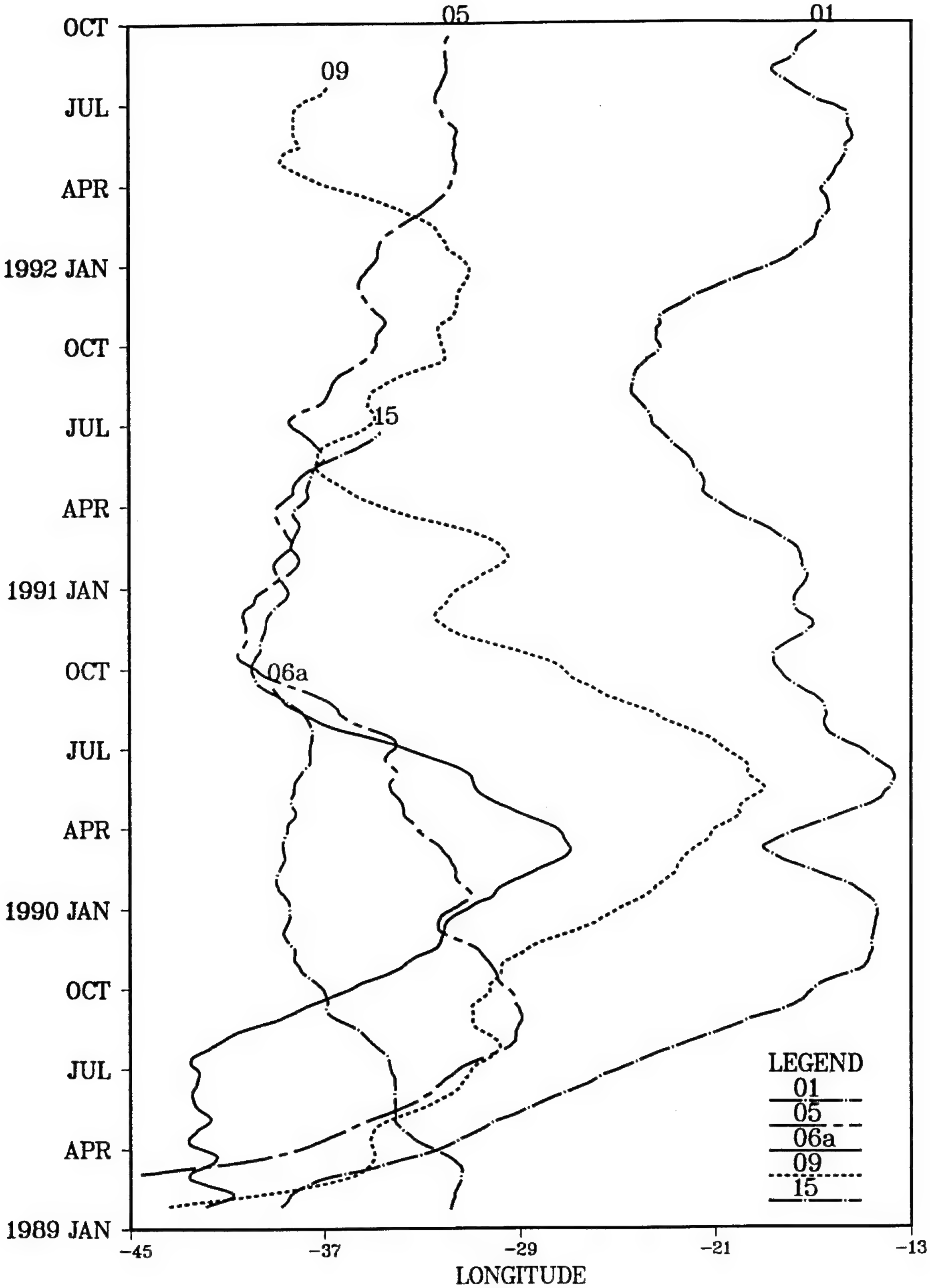
800m Equatorial Floats Time – Longitude



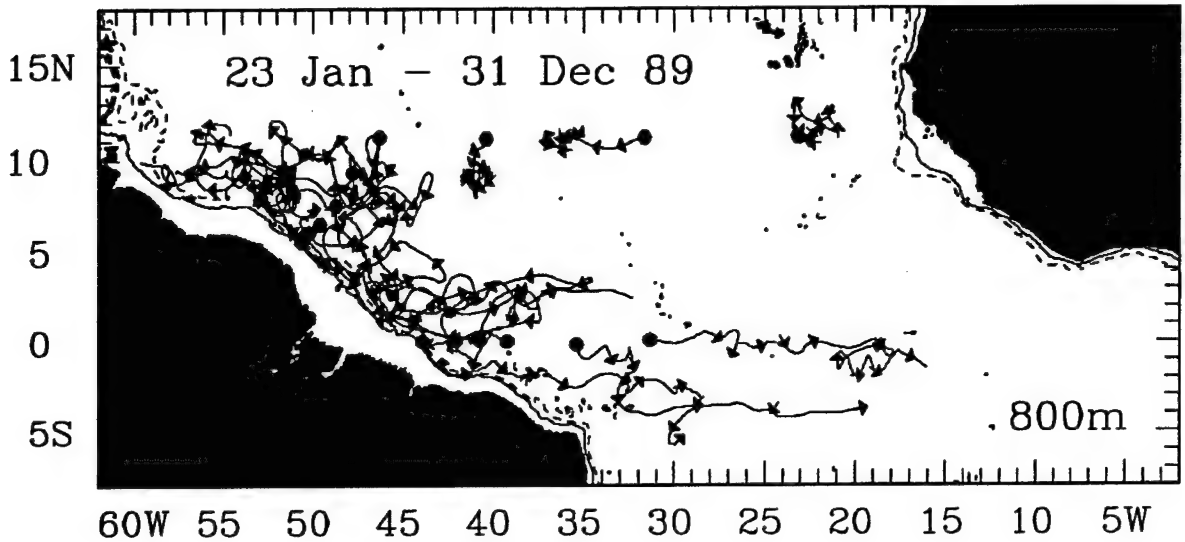


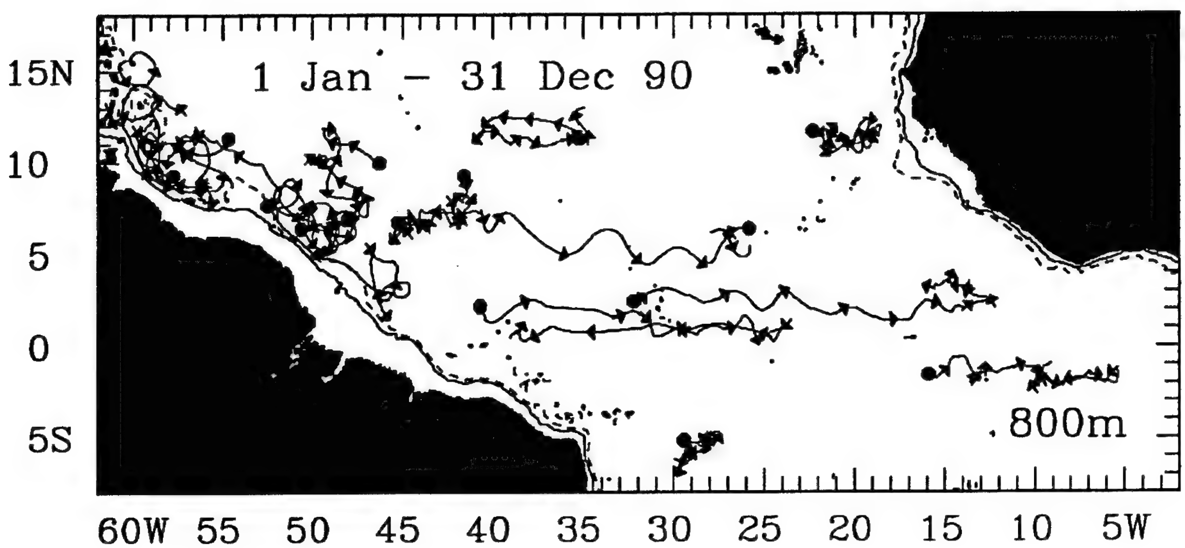
1800m Equatorial Floats Time – Latitude
05
01
14
09
06b
15
13
06a
OCT
JUL
APR
1992 JAN
OCT
JUL
APR
1991 JAN
OCT
JUL
APR
1990 JAN
OCT
JUL
APR
1989 JAN
5
2.5
0
–2.5
–5
LATITUDE
LEGEND
01
05
06a
06b
09
13
14
15

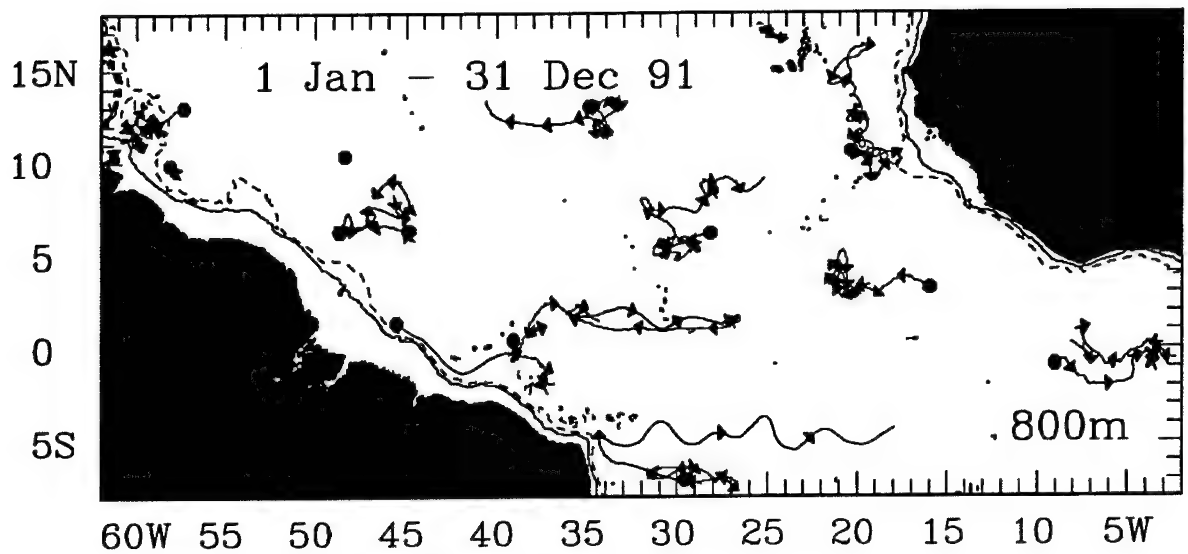
1800m Equatorial Floats Time – Longitude

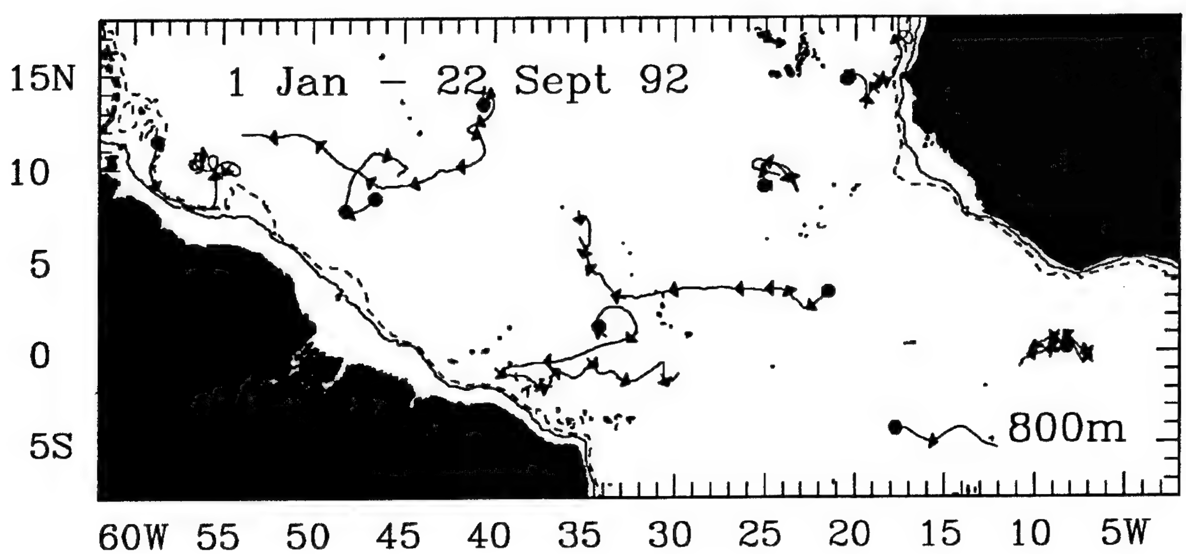


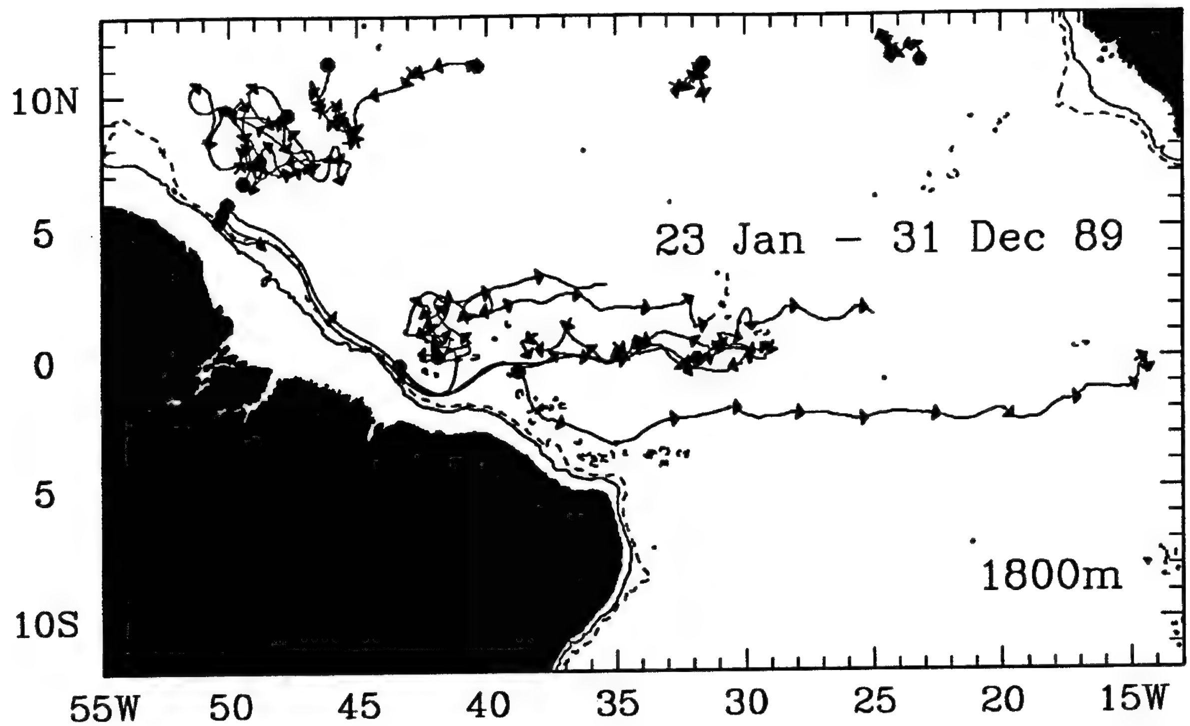
Yearly Composites

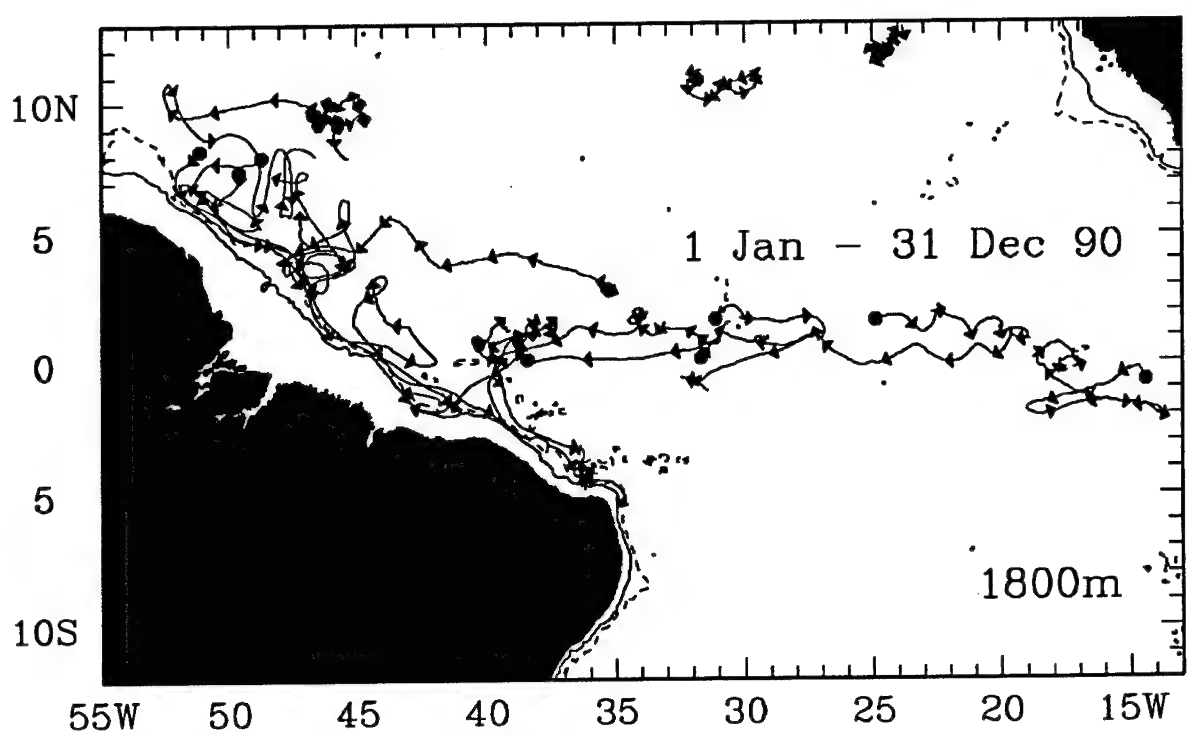


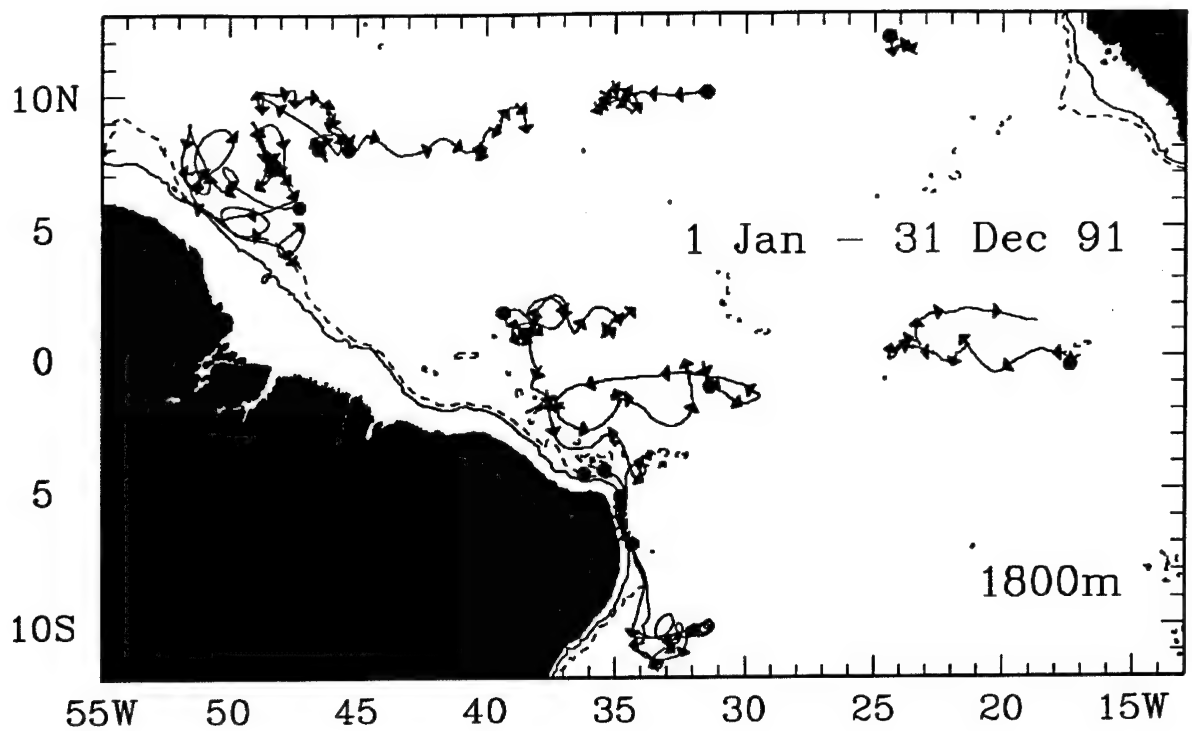



1 Jan - 31 Dec 91
800m
15N
10
5
0
5S
60W 55 50 45 40 35 30 25 20 15 10 5W


1 Jan - 22 Sept 92
800m
15N
10
5
0
5S
60W 55 50 45 40 35 30 25 20 15 10 5W


10N
5
0
5
10S
23 Jan – 31 Dec 89
1800m
55W
50
45
40
35
30
25
20
15W


10N
5
0
5
10S
1 Jan – 31 Dec 90
1800m
55W
50
45
40
35
30
25
20
15W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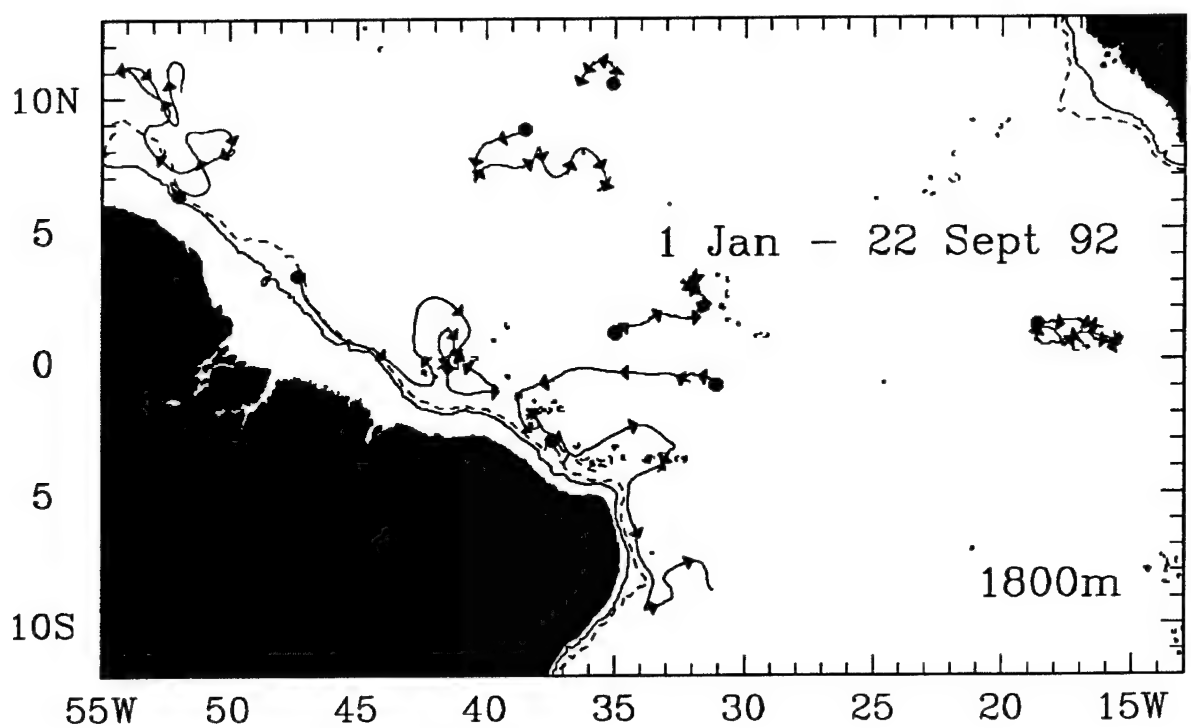
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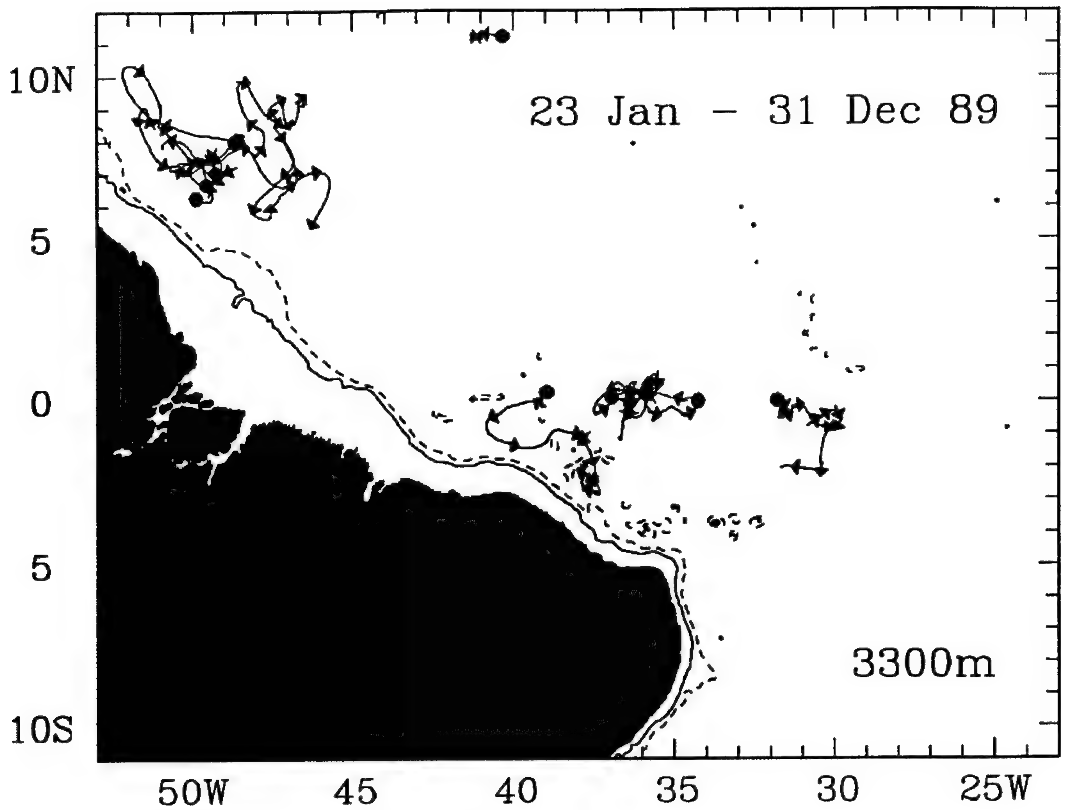
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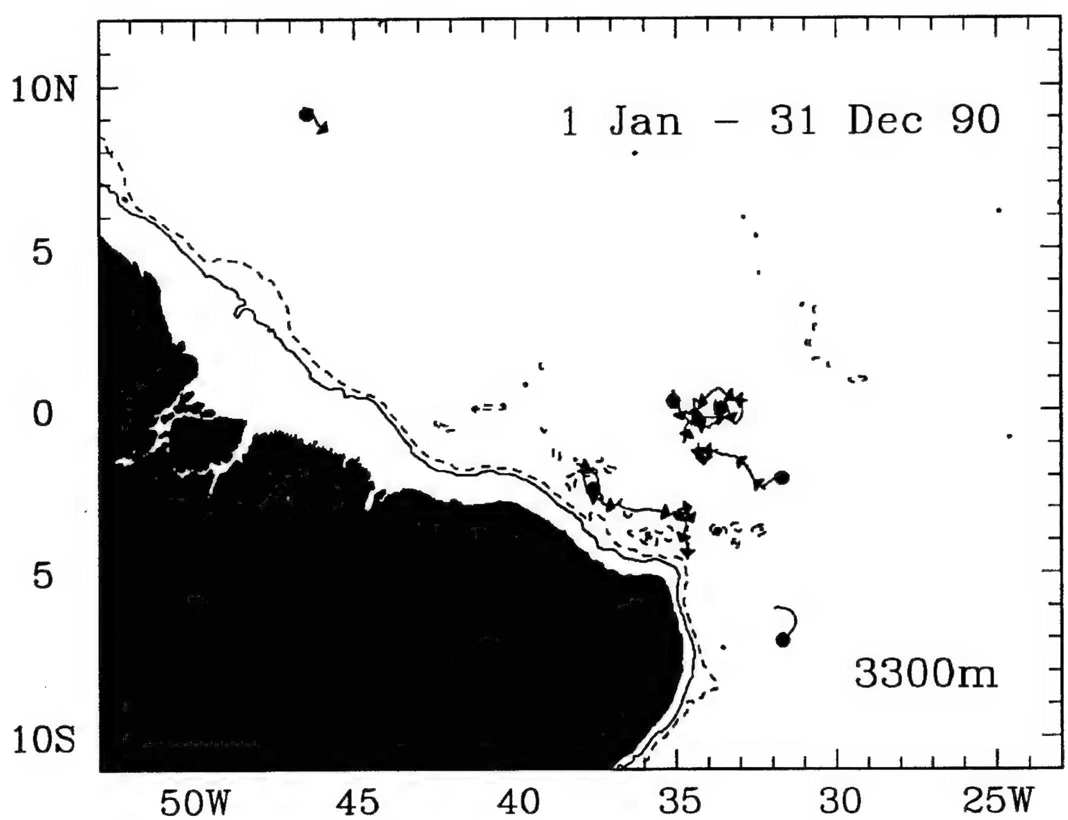
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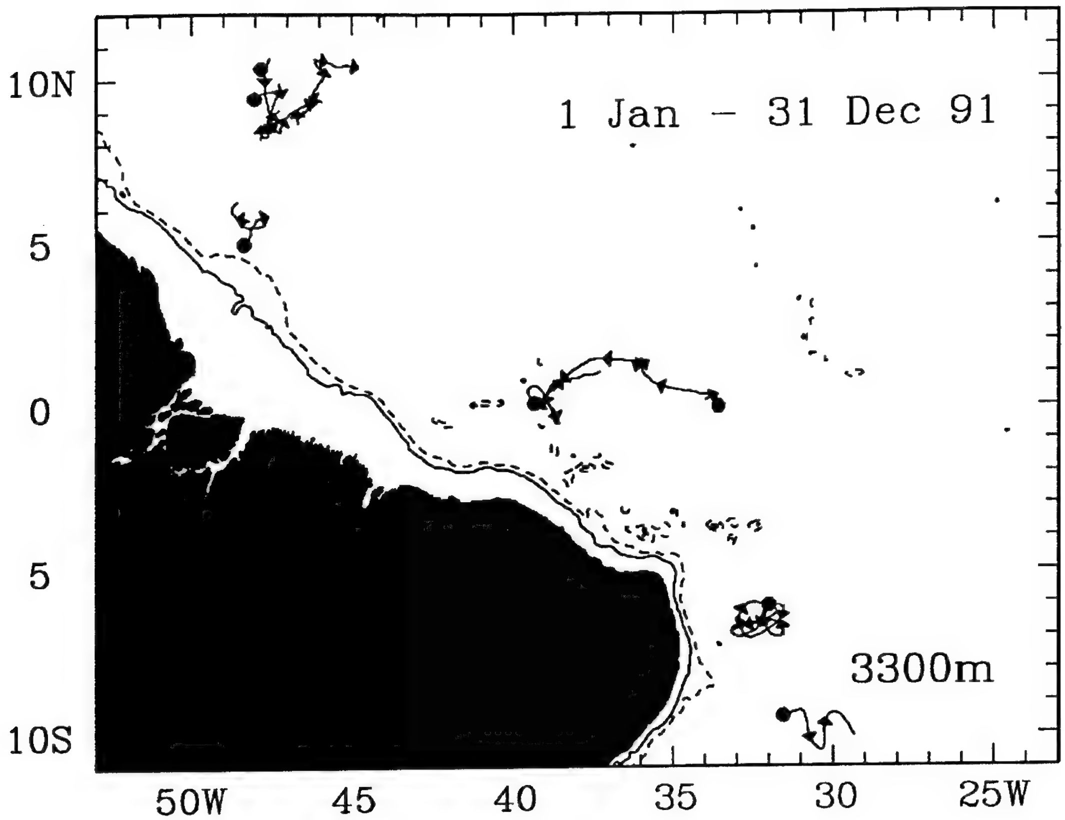

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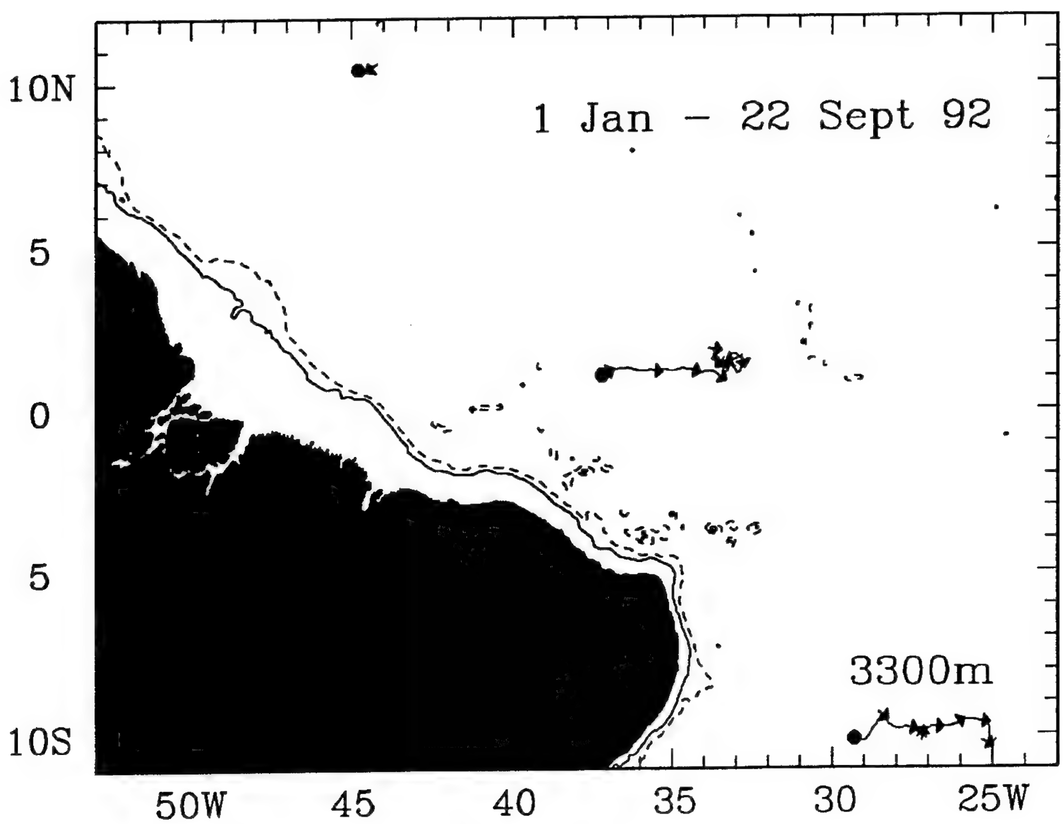

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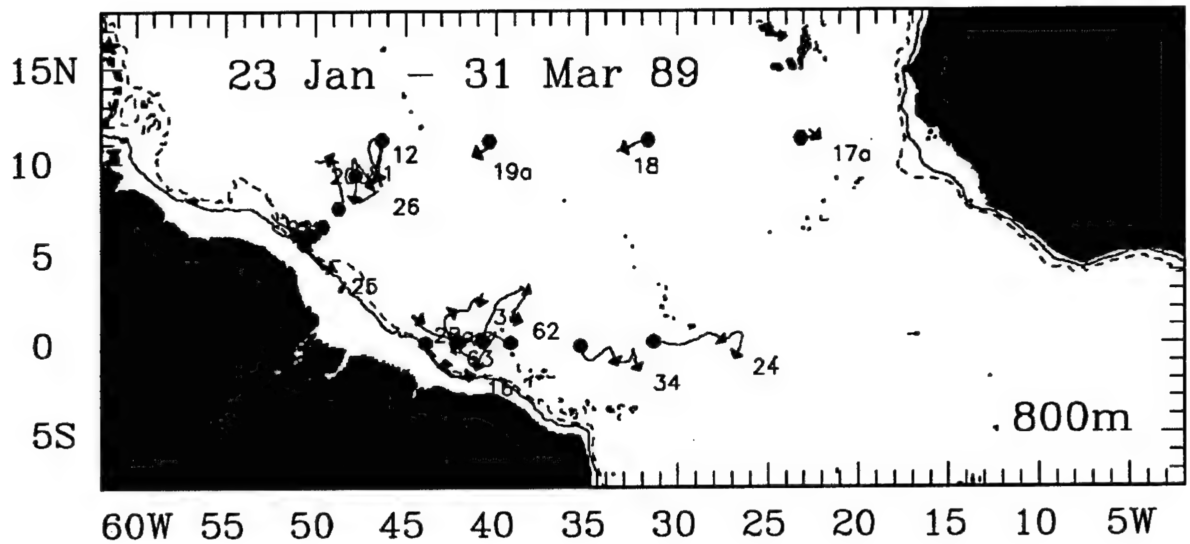
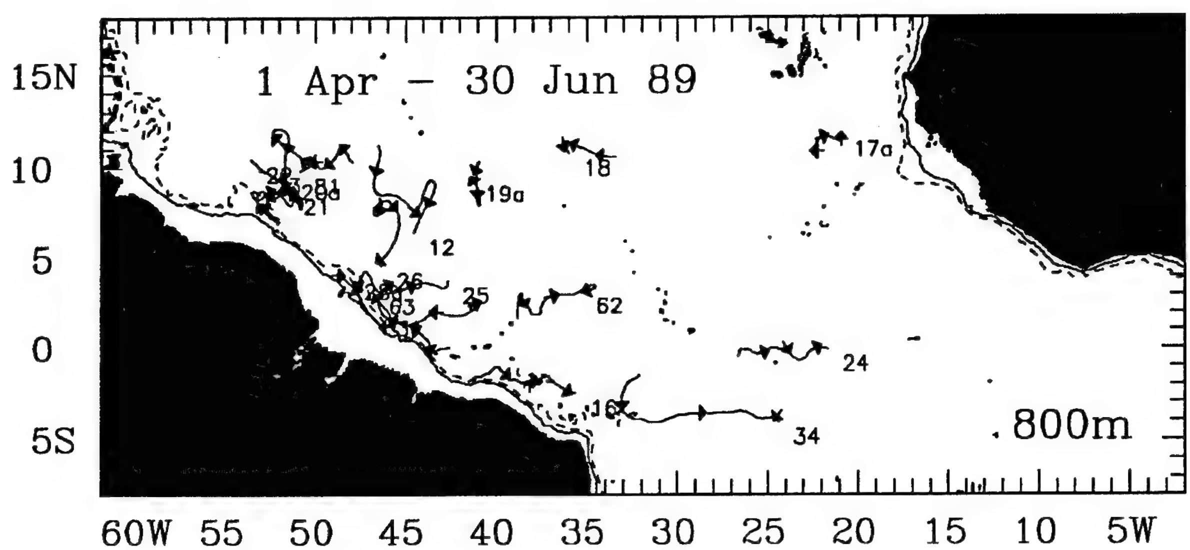
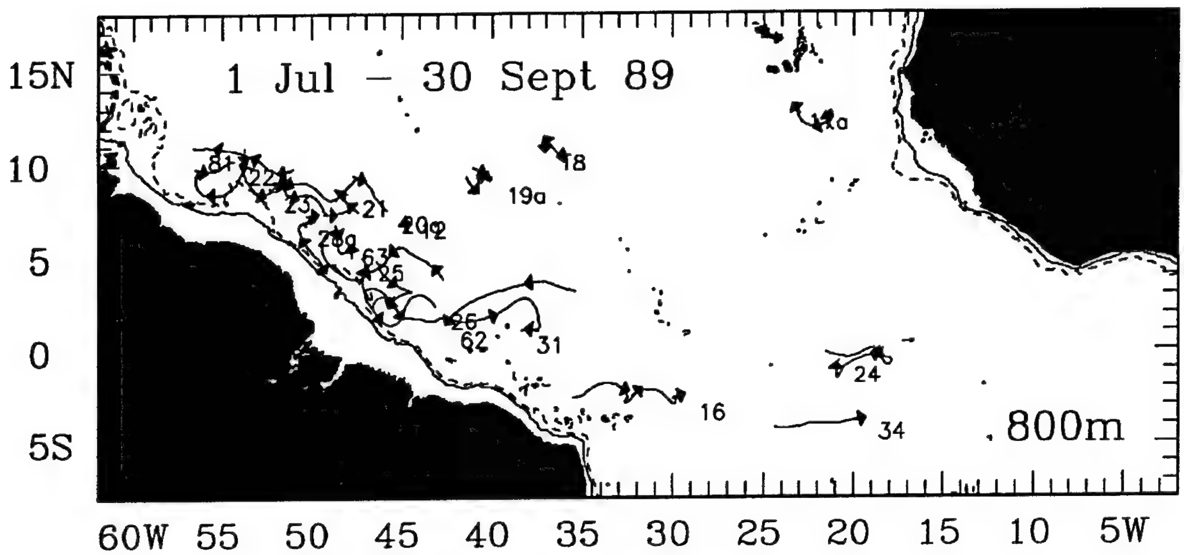
Three-Month Composites



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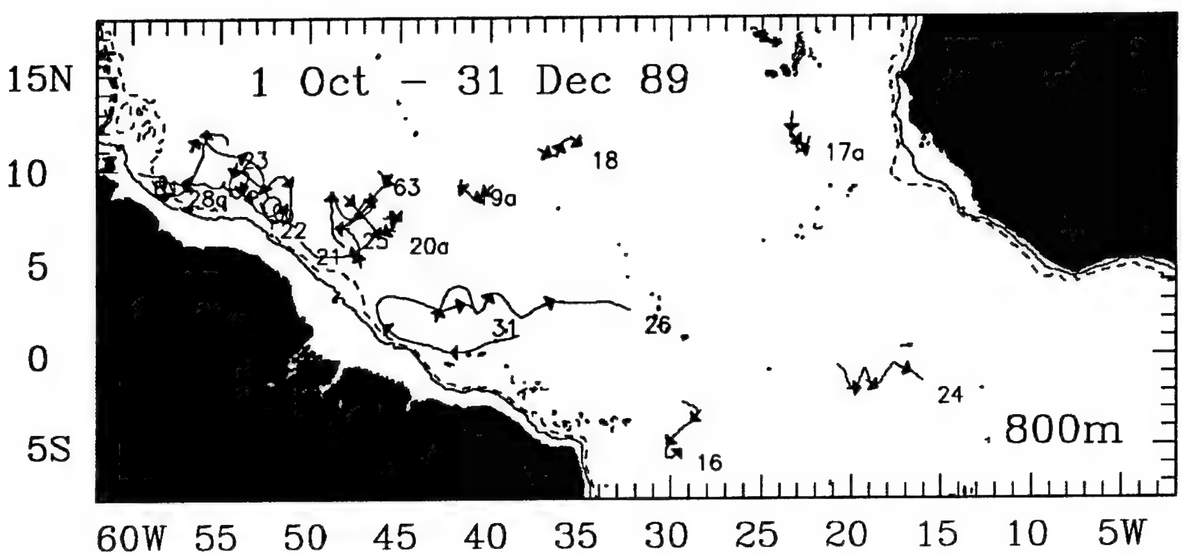
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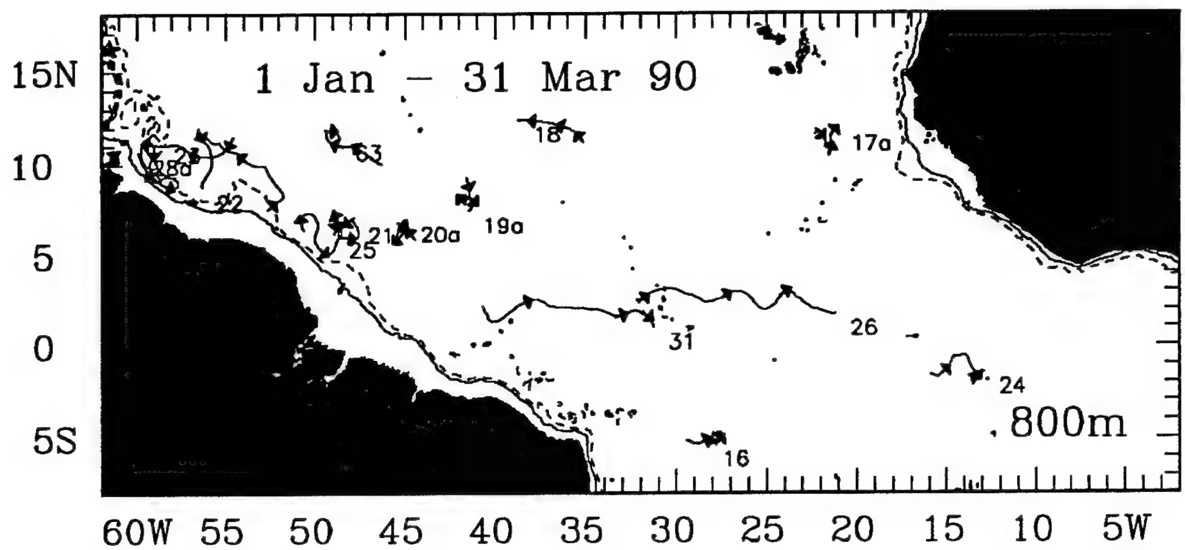

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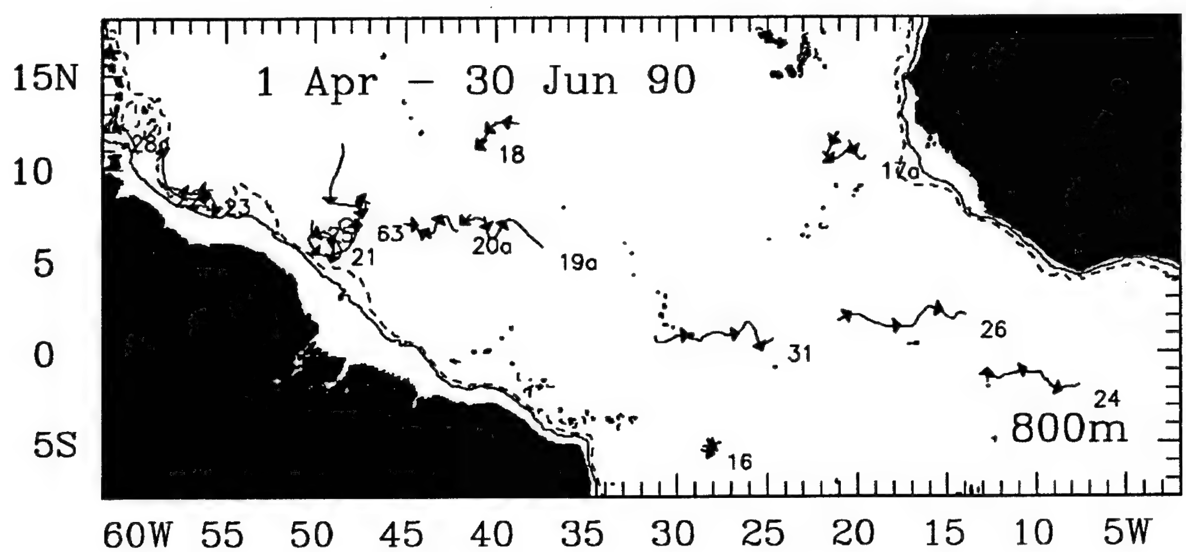

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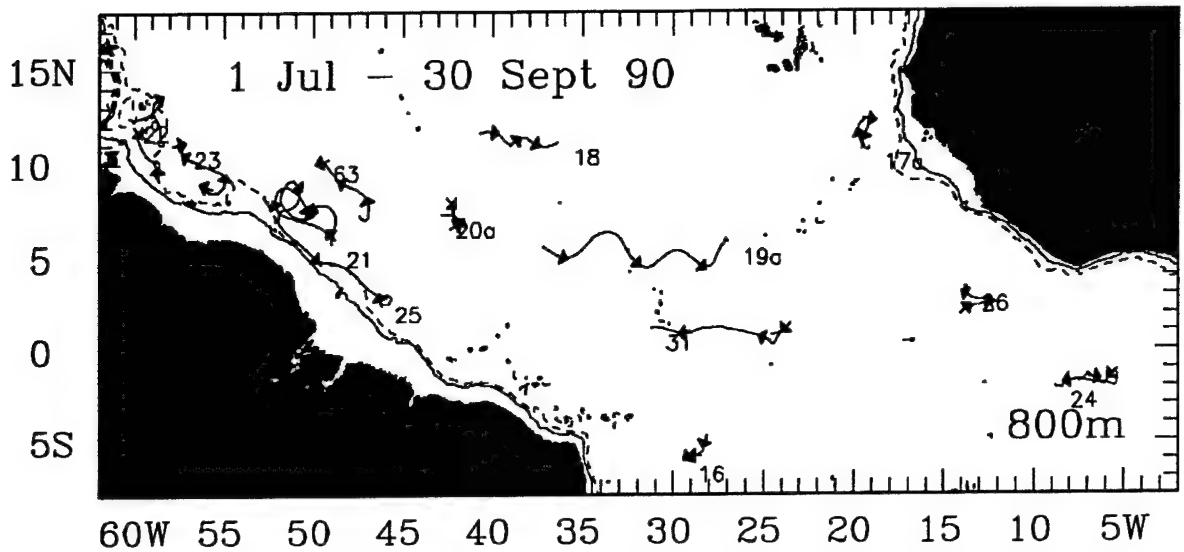
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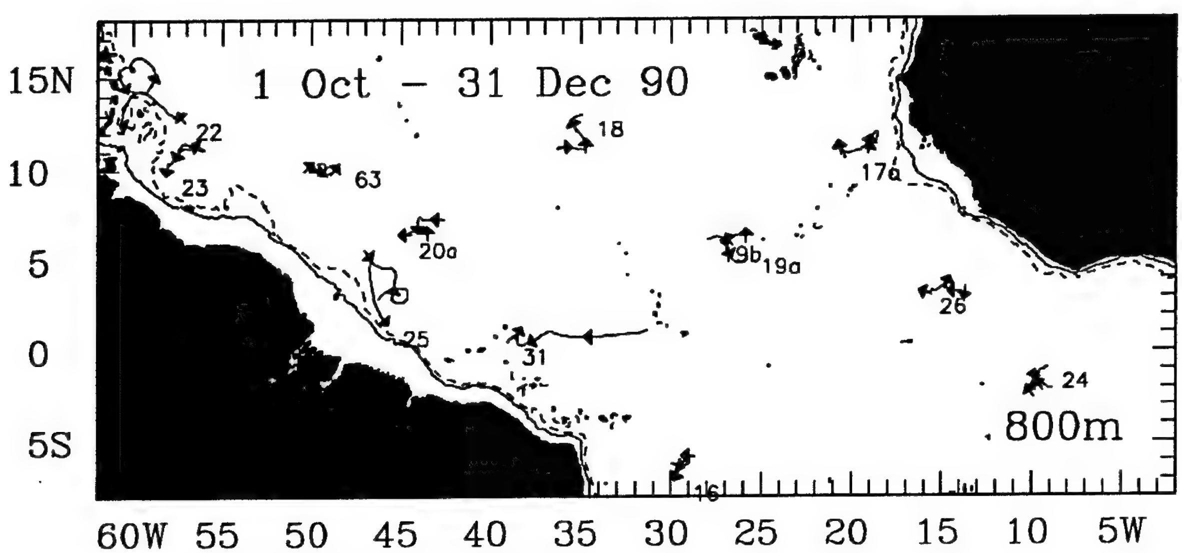
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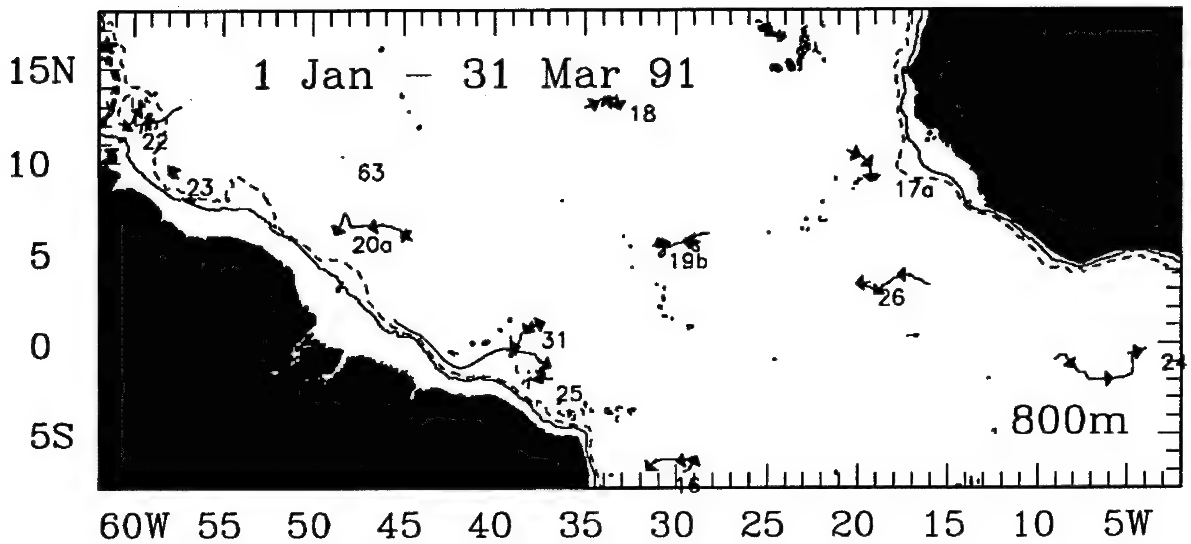
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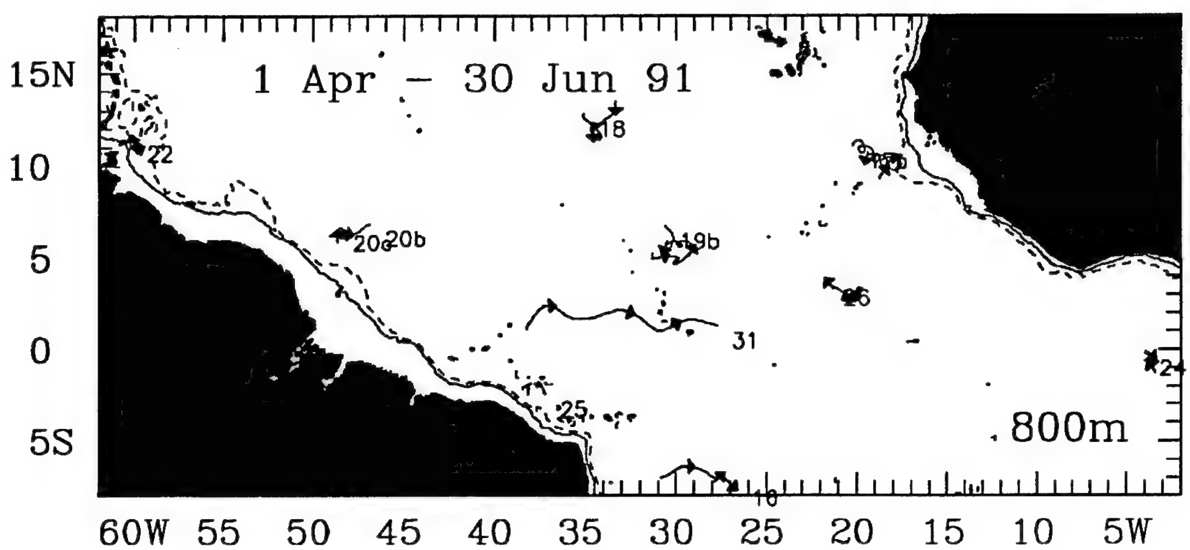
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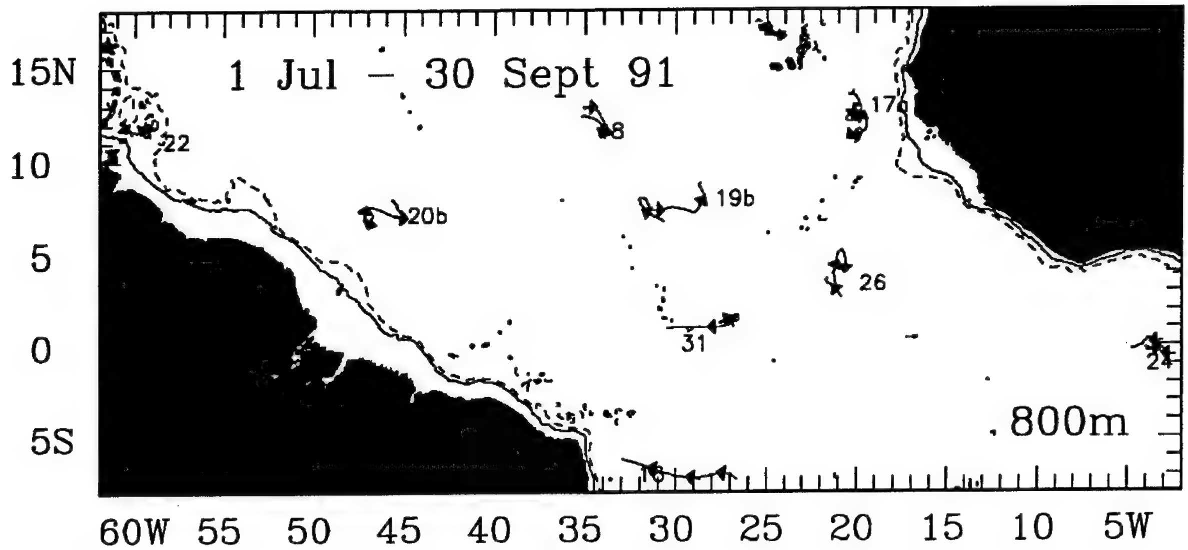
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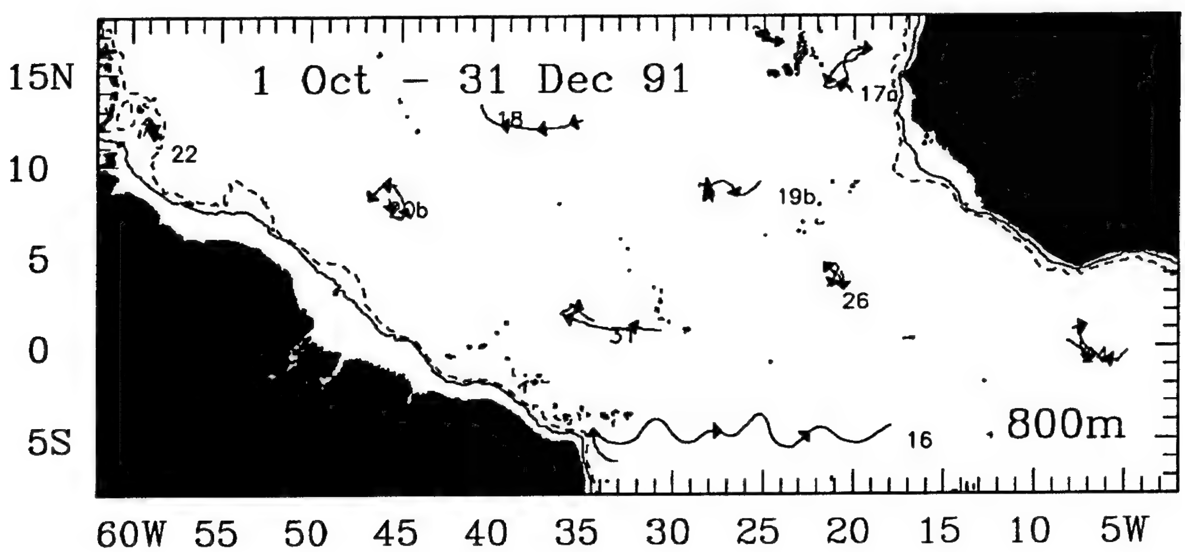
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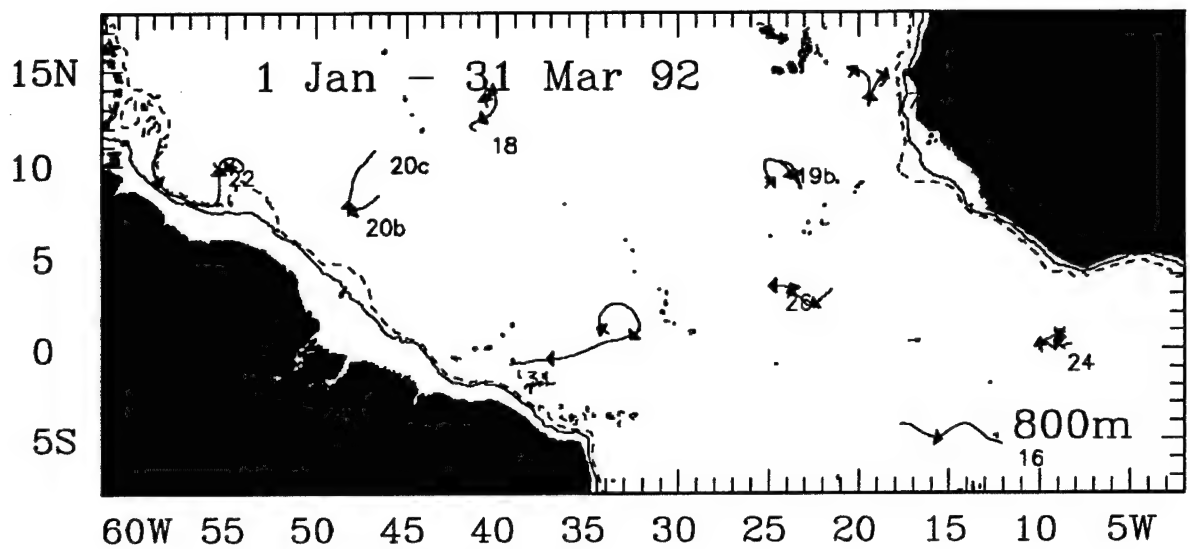
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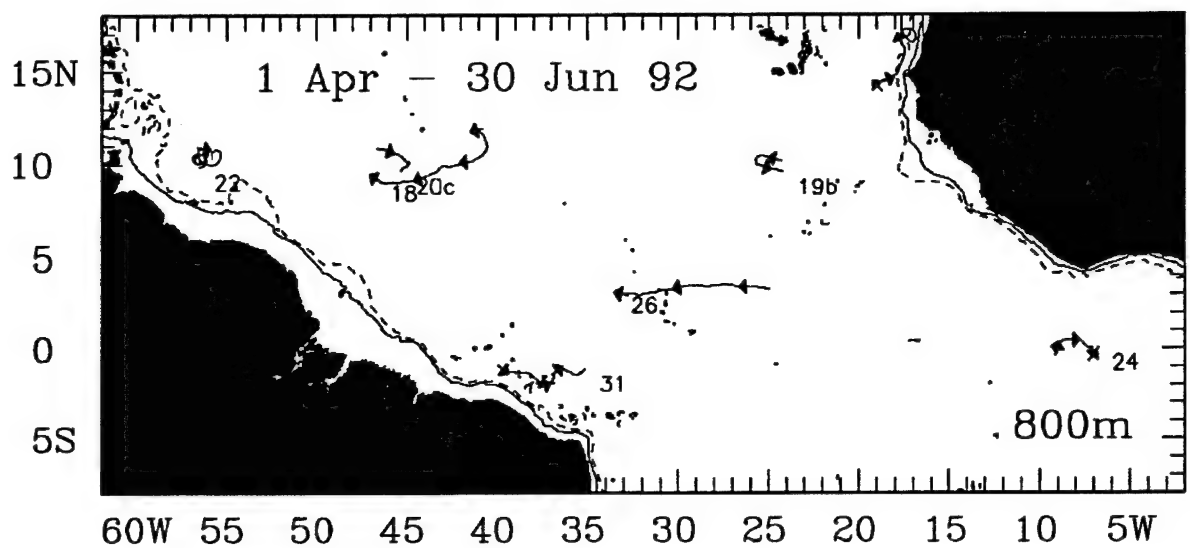
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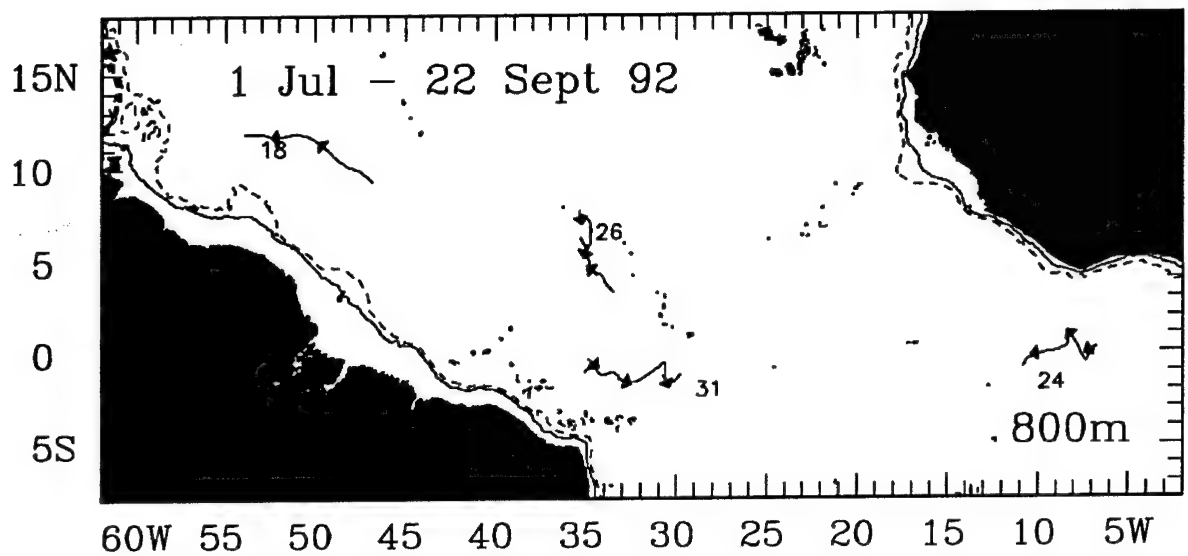

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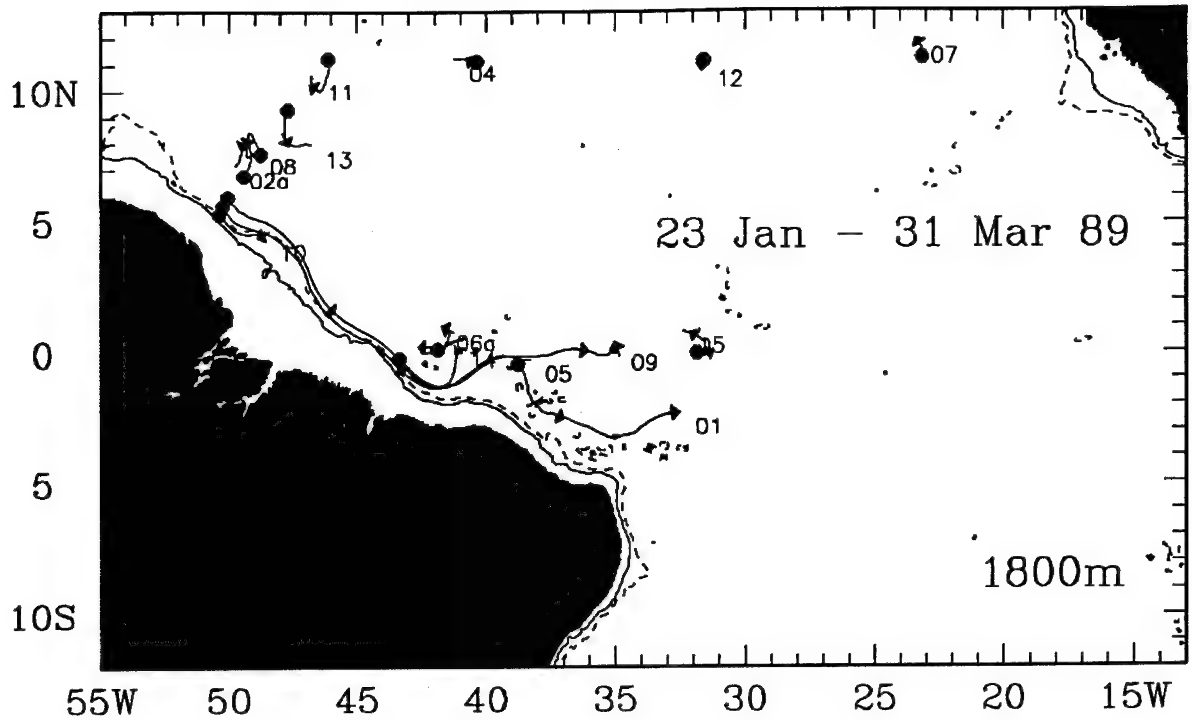
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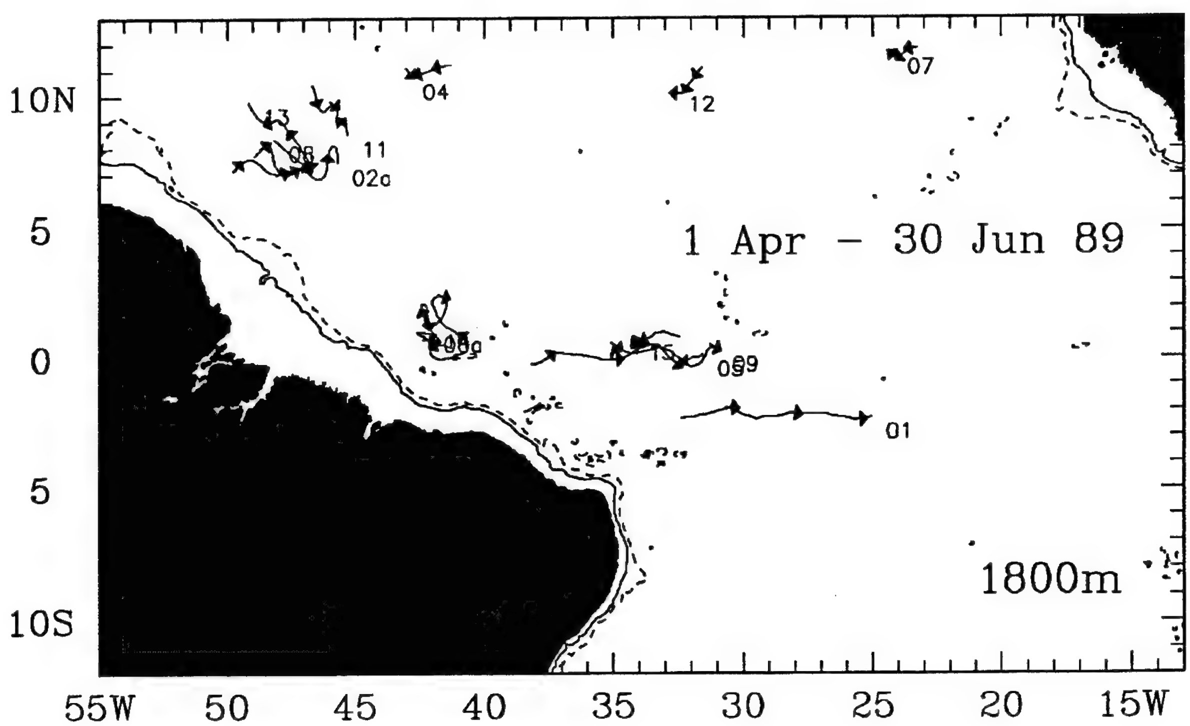
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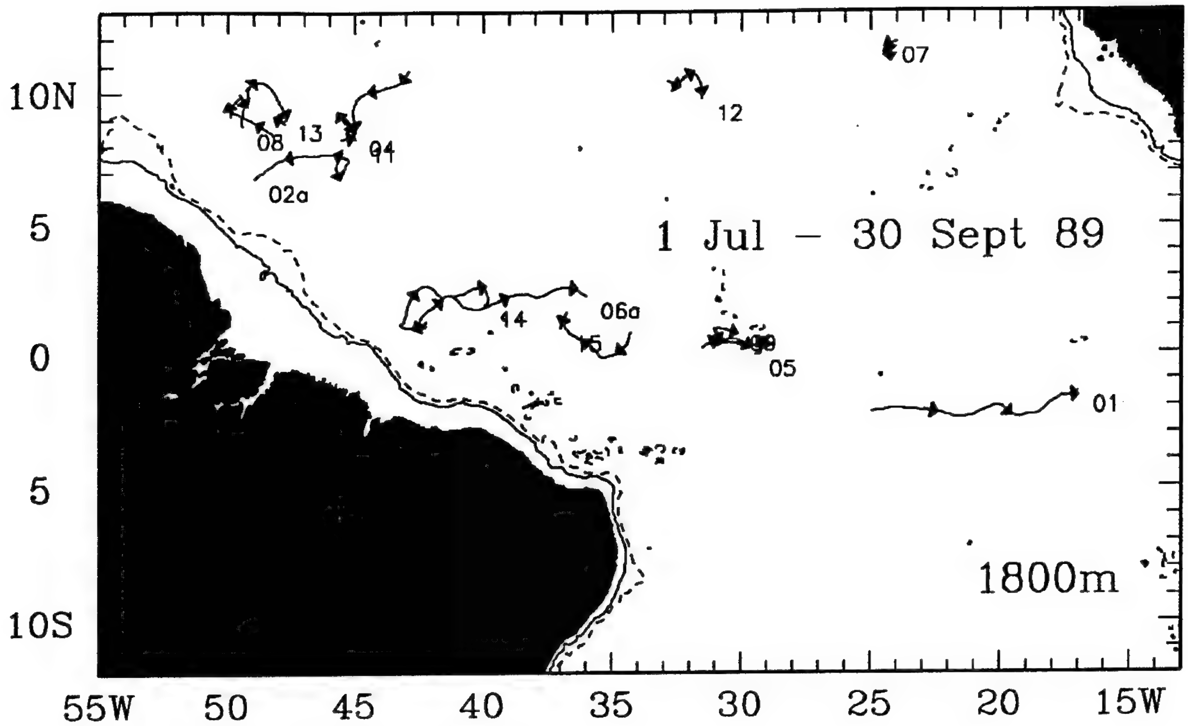
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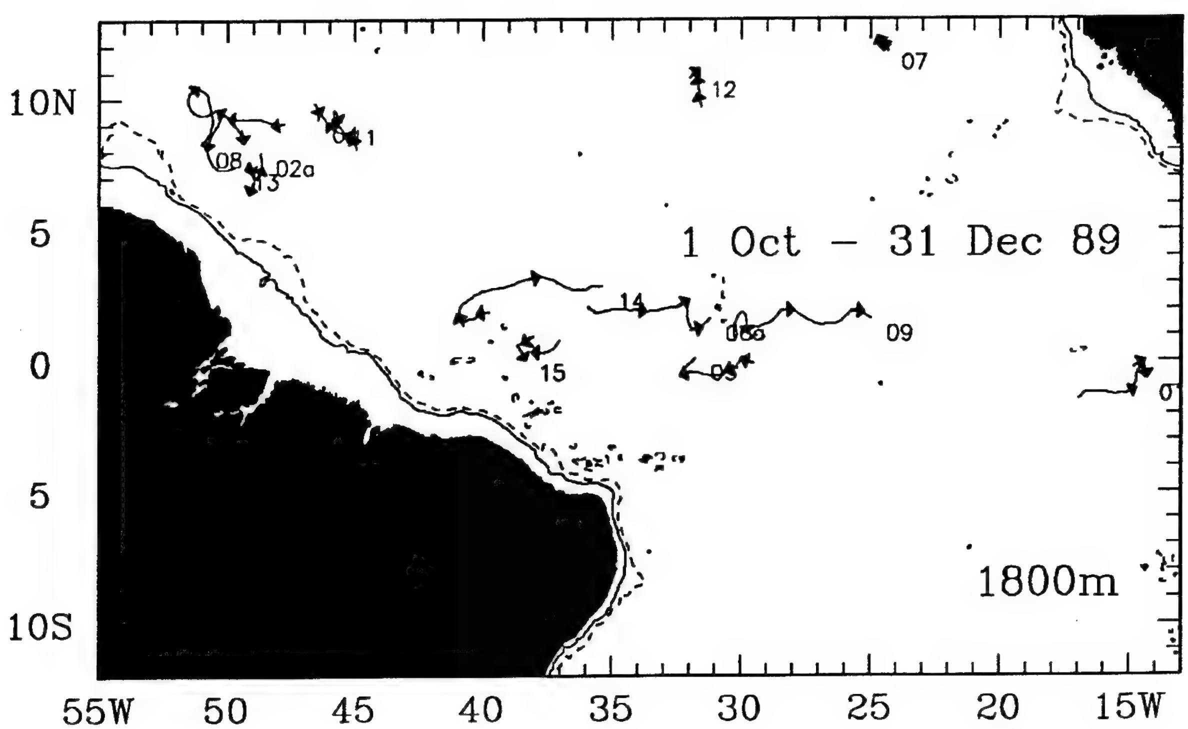
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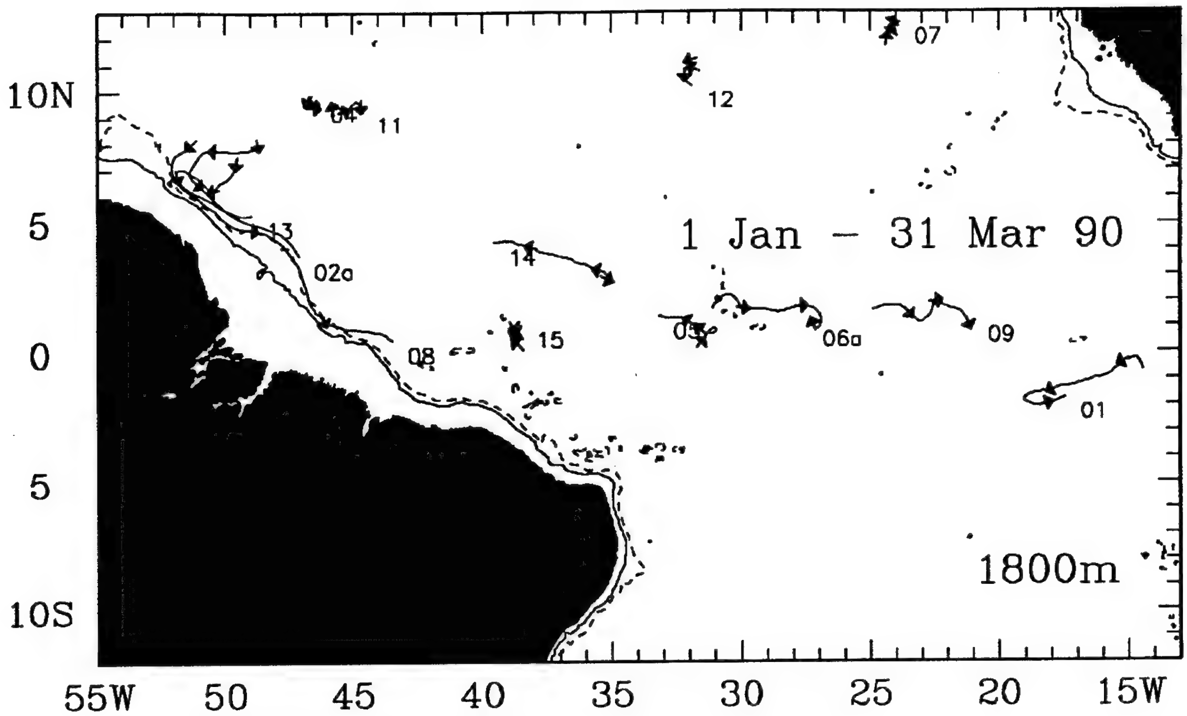
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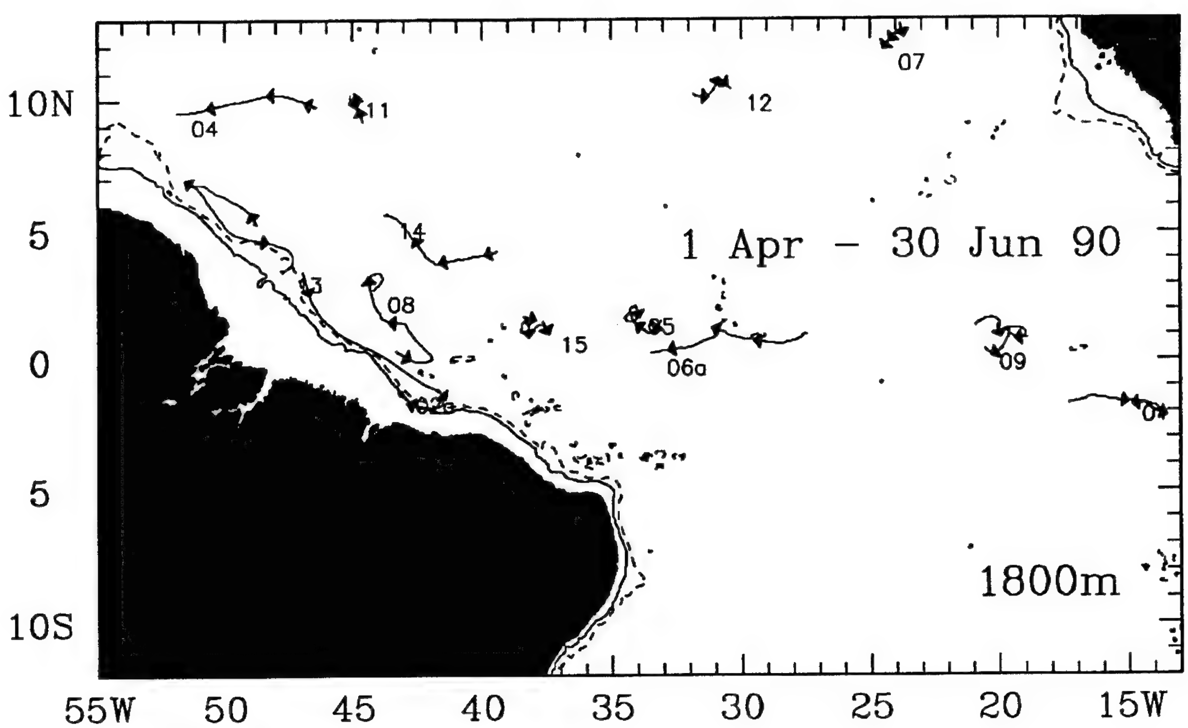
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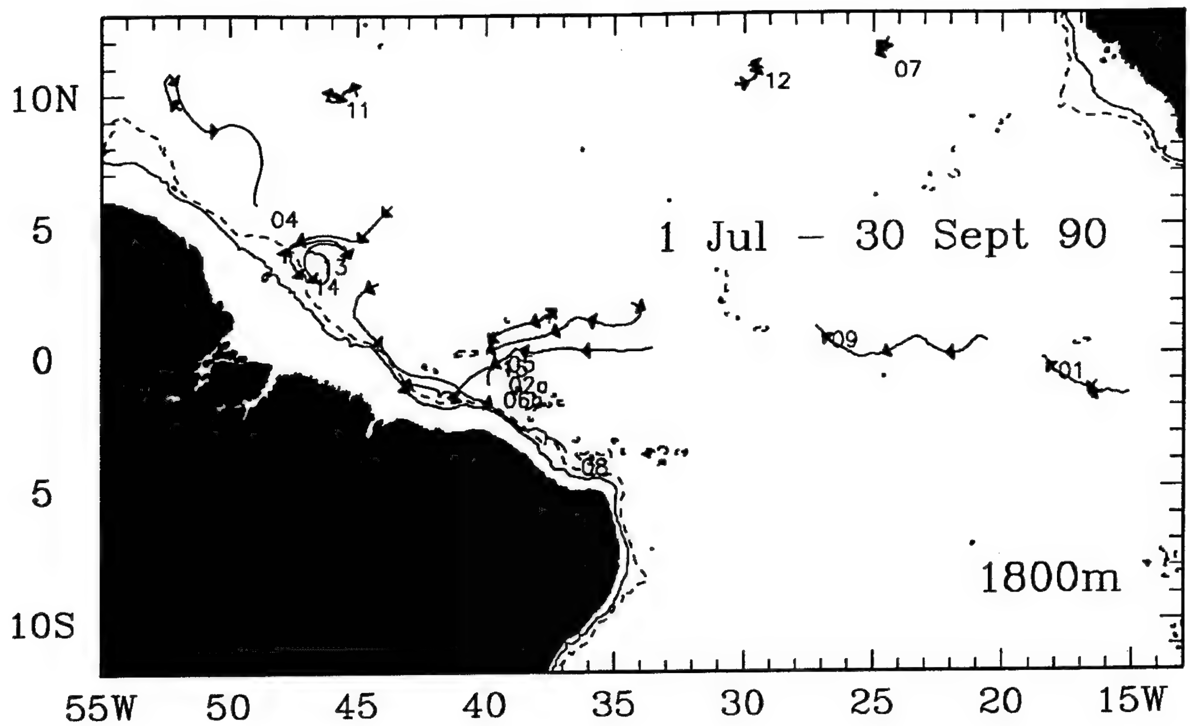
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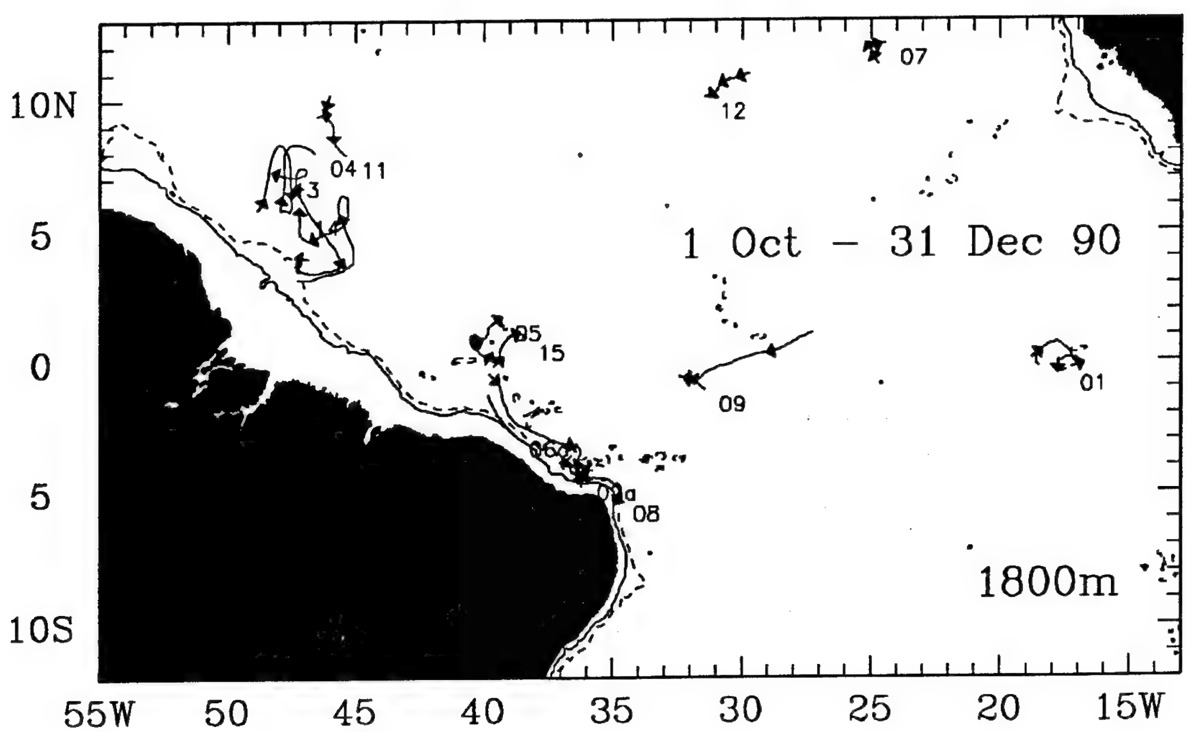
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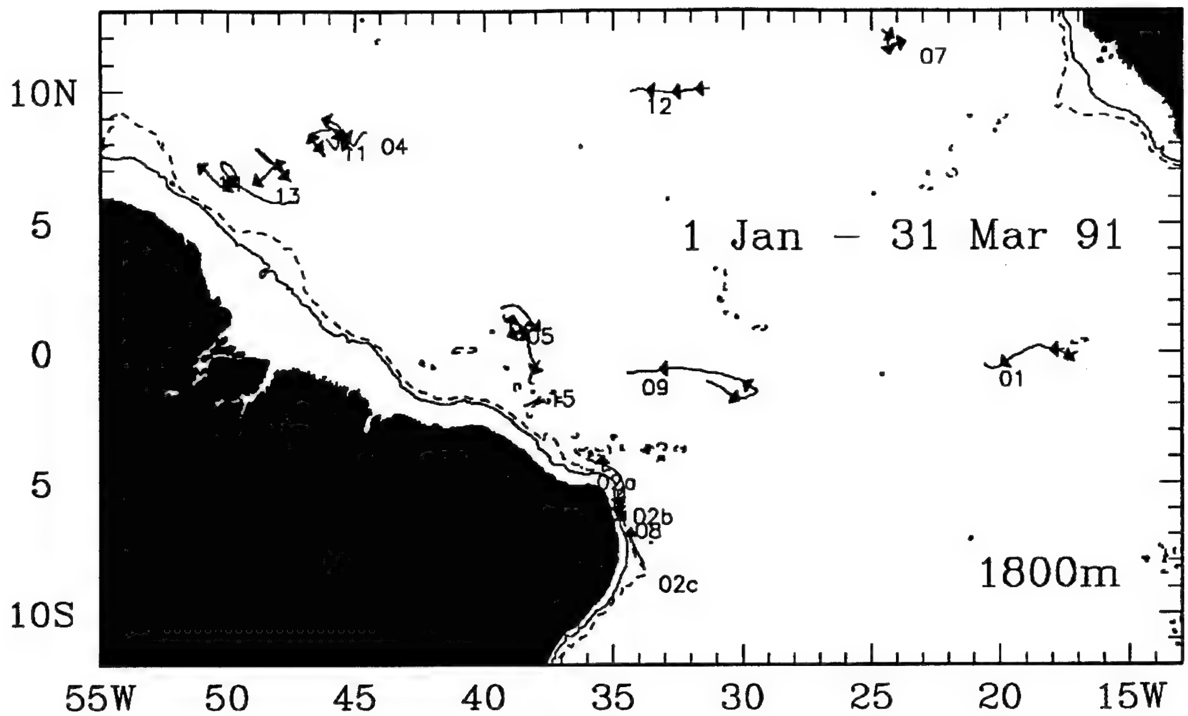
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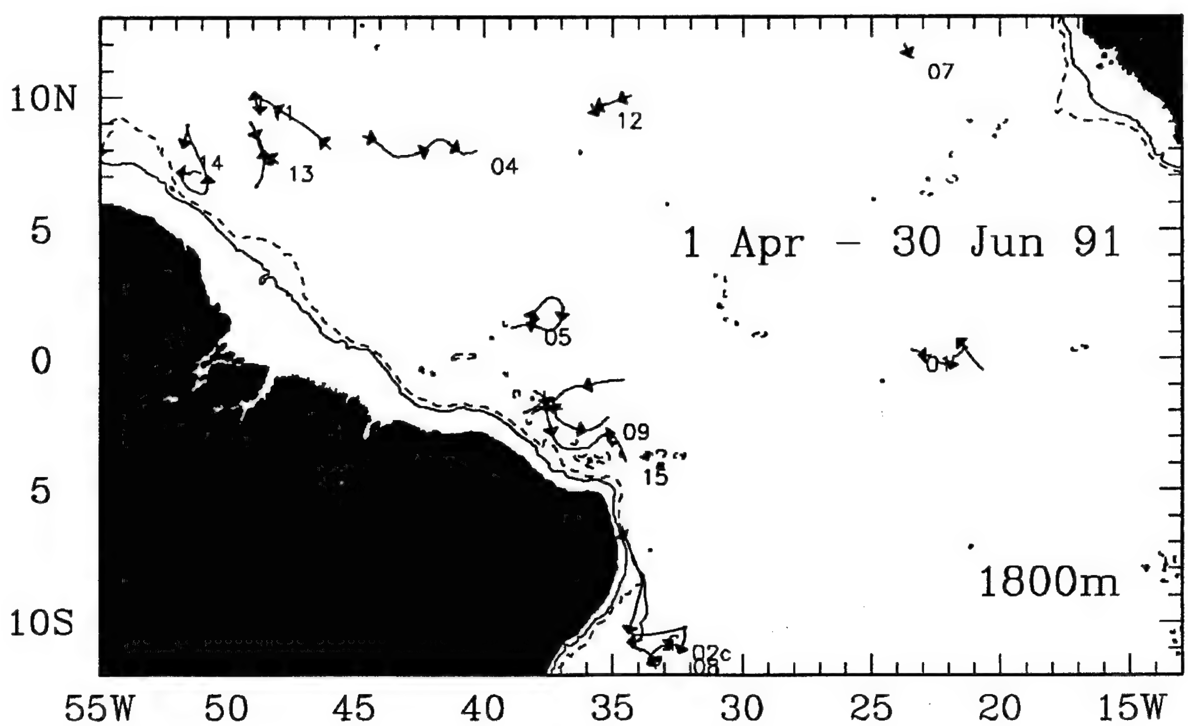
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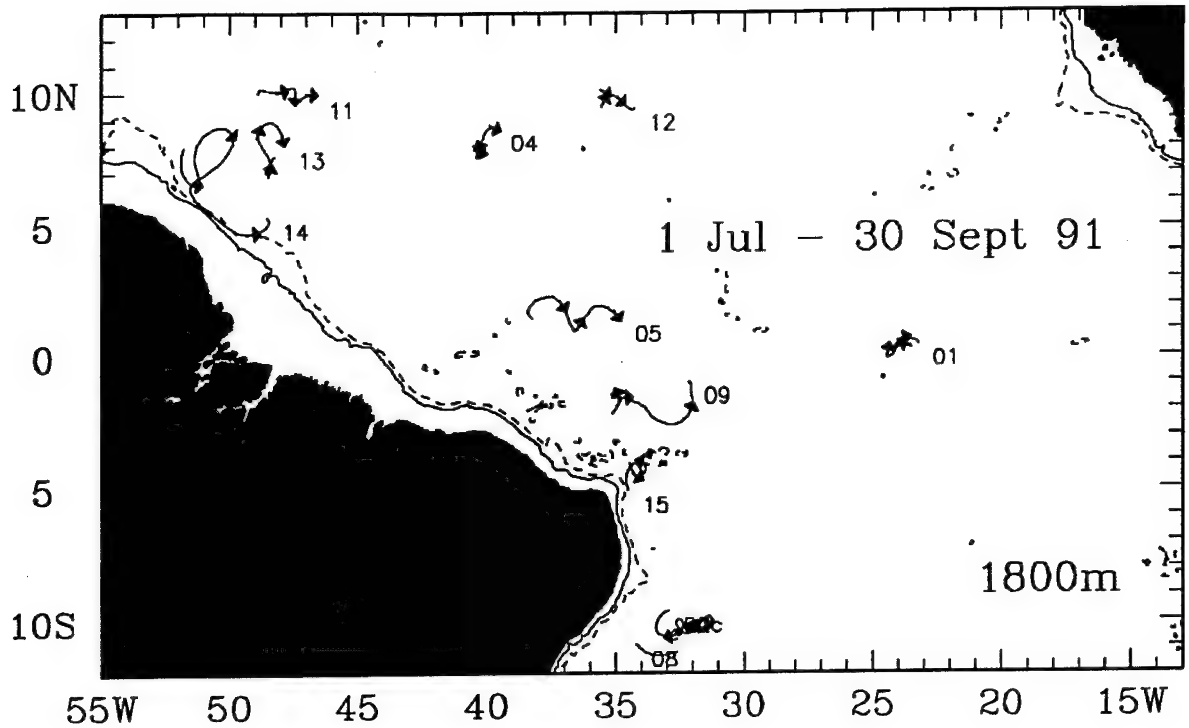
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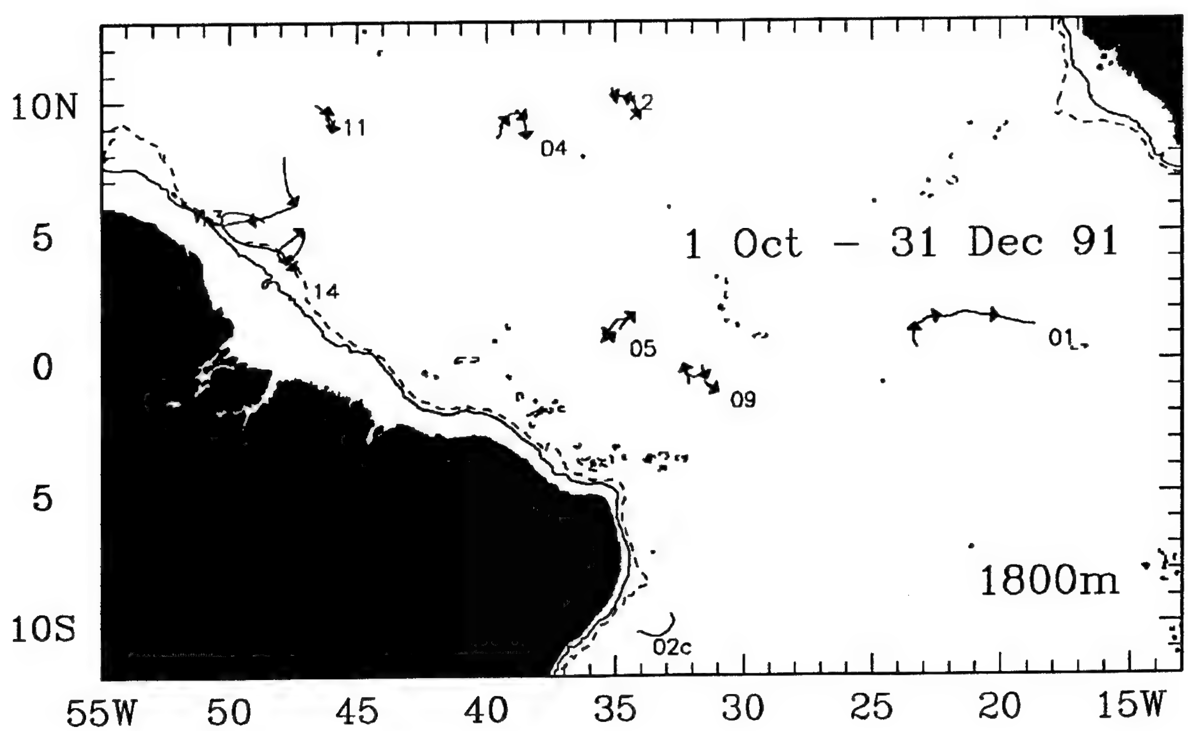
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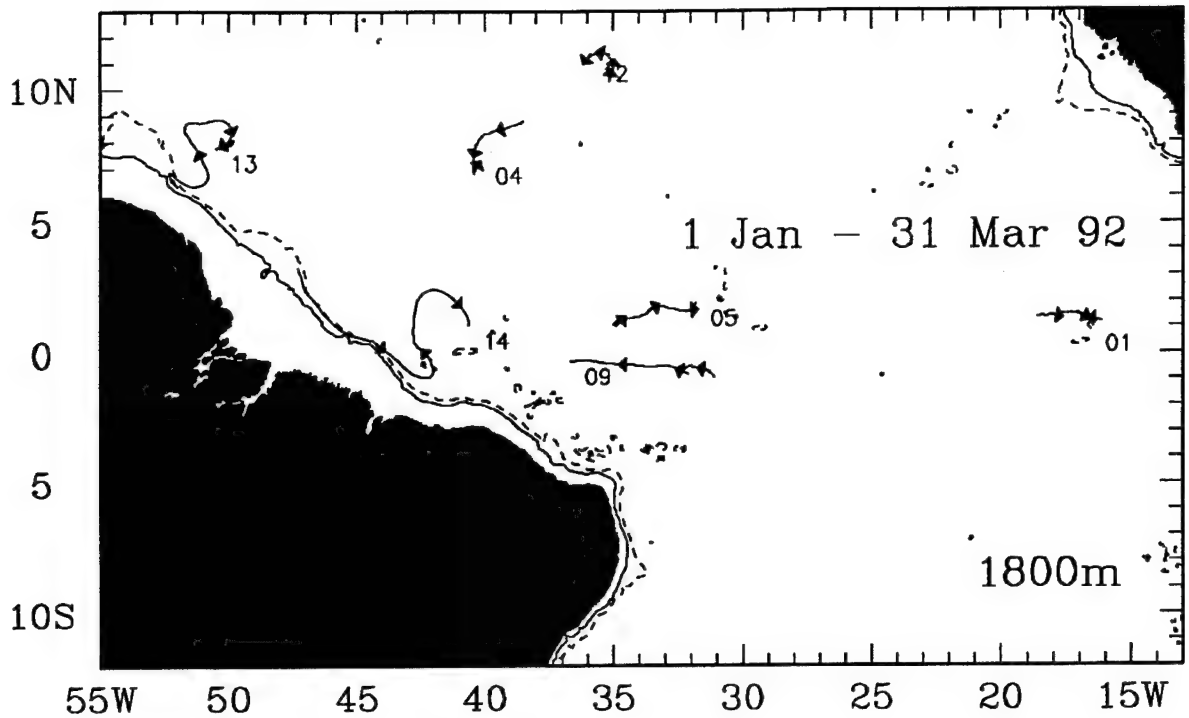
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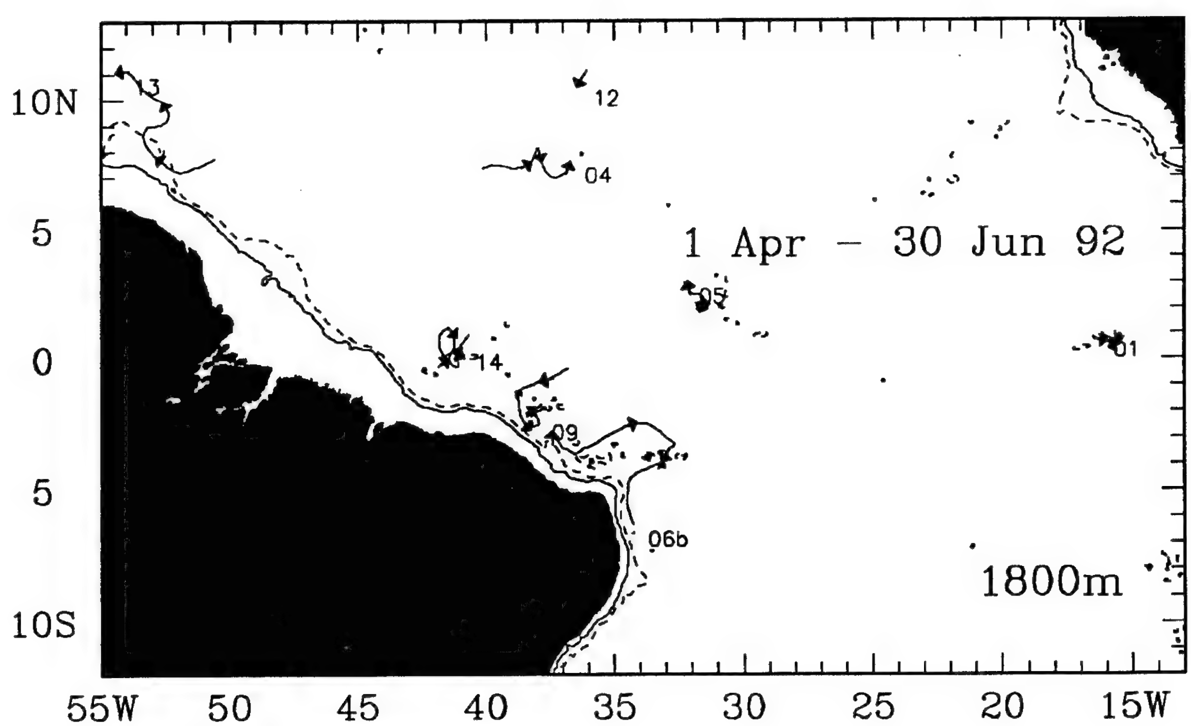
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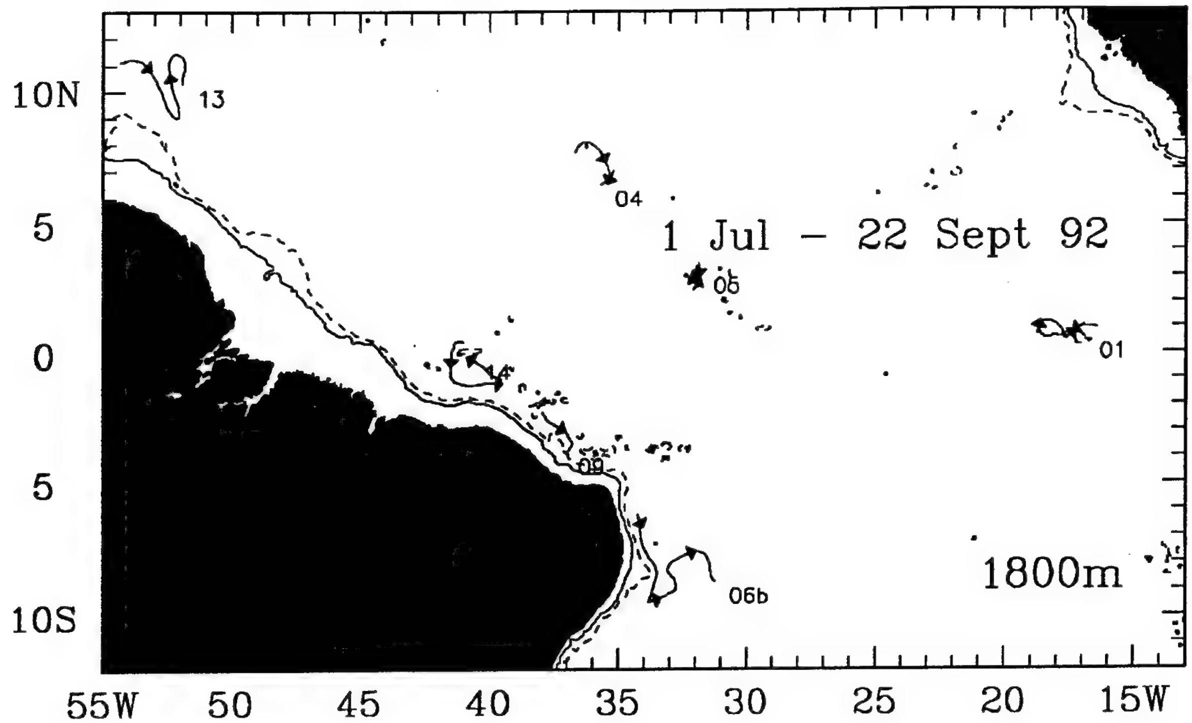
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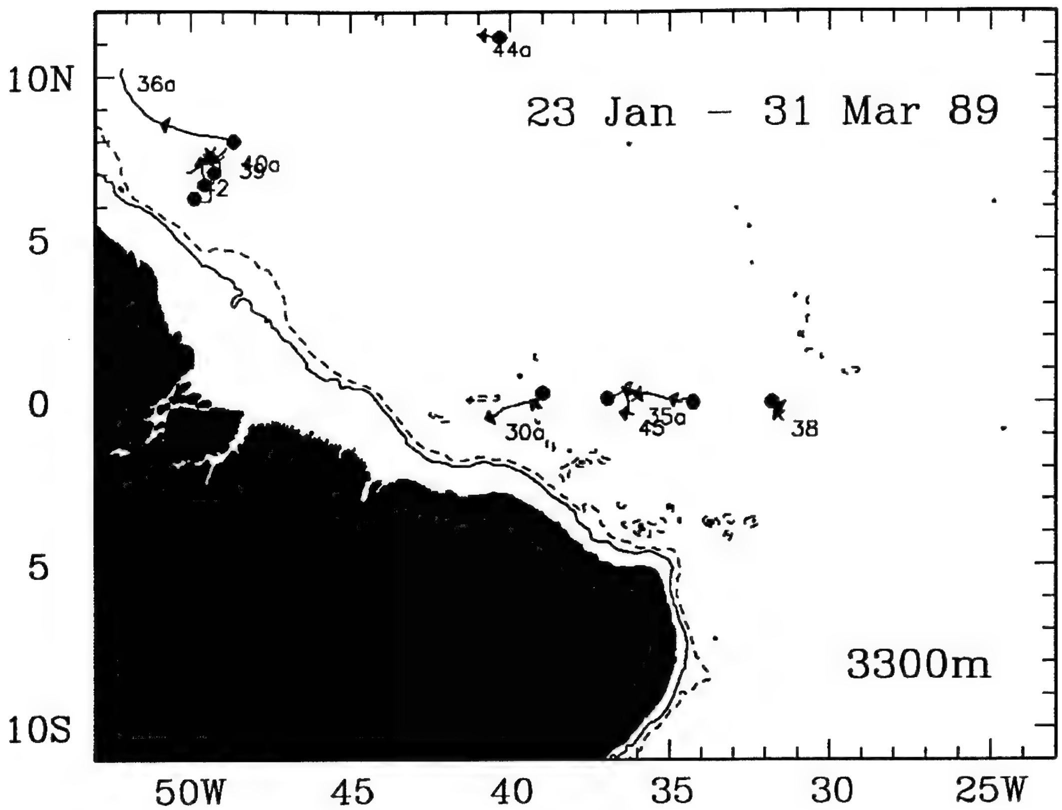
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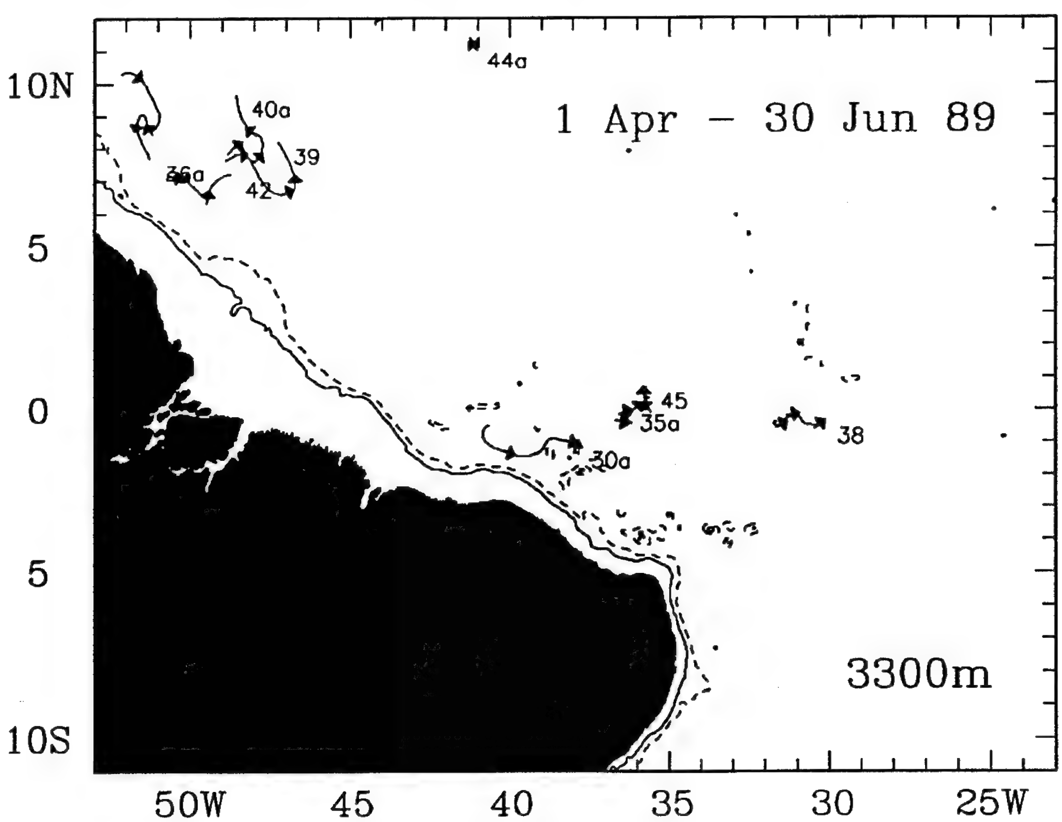
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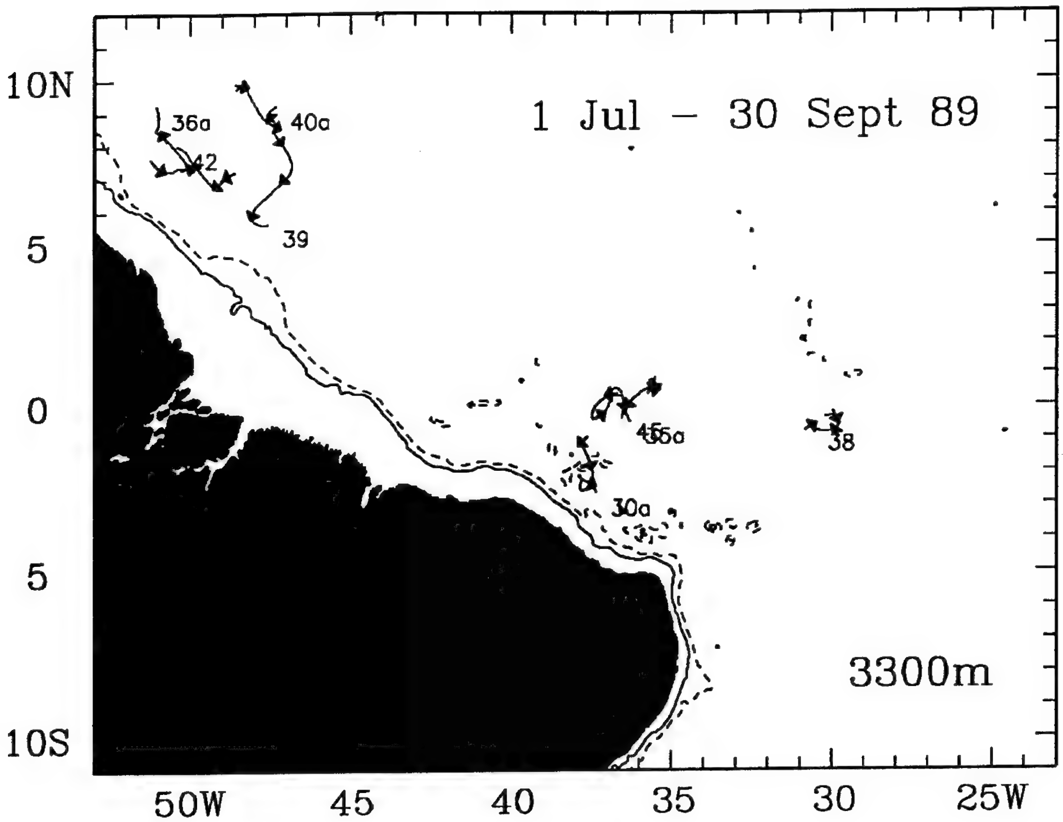
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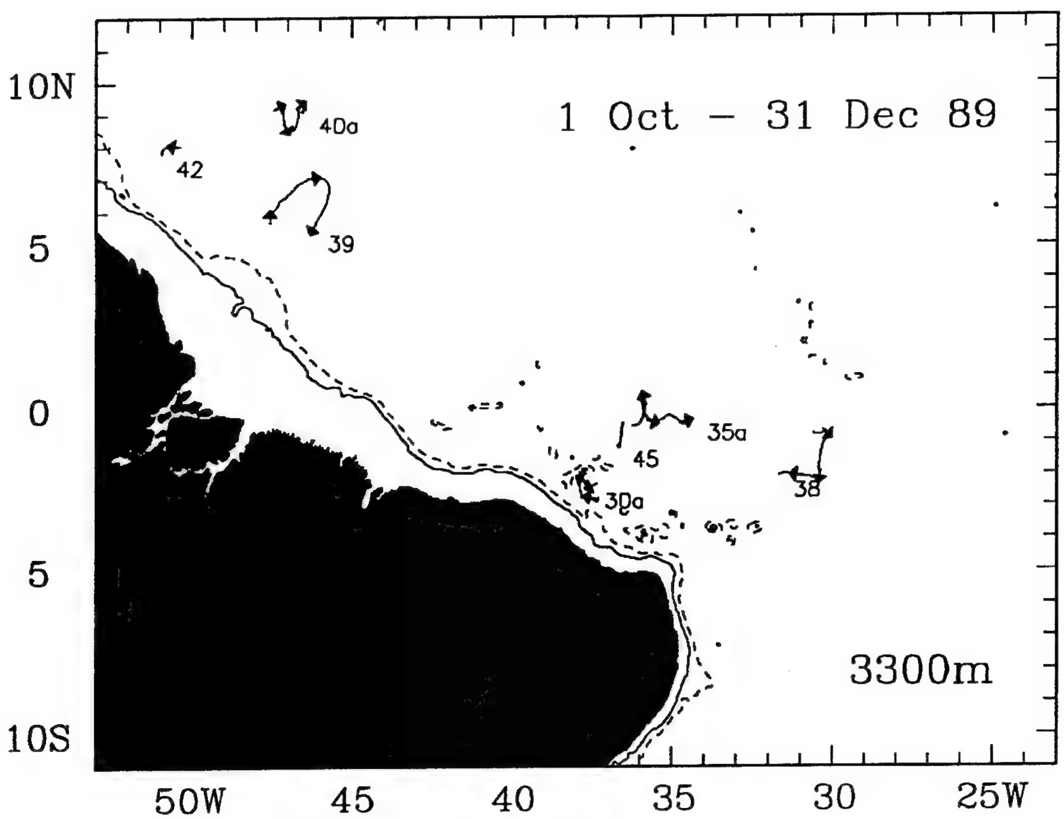
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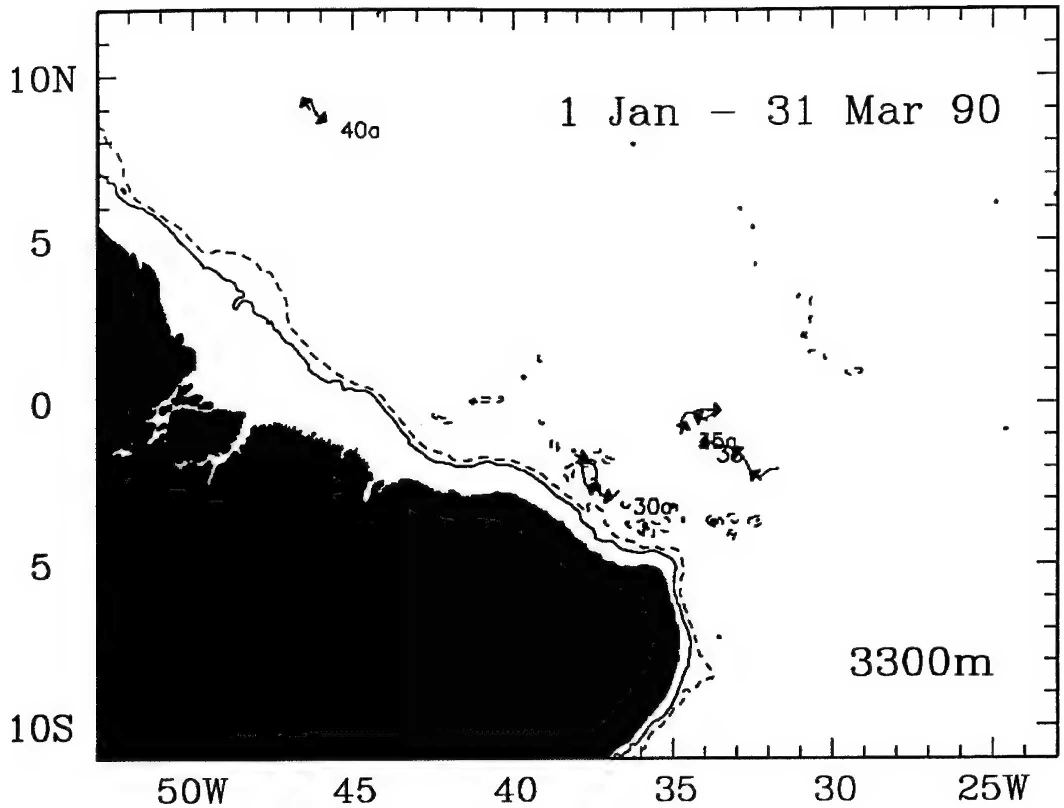
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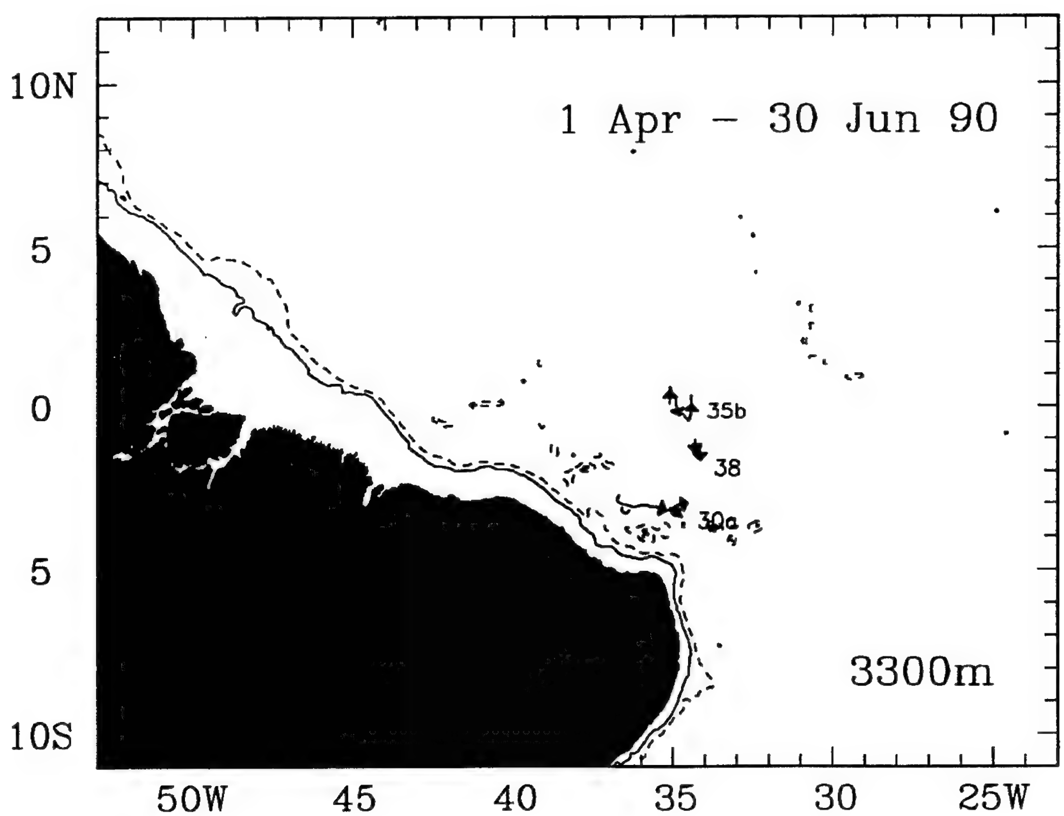
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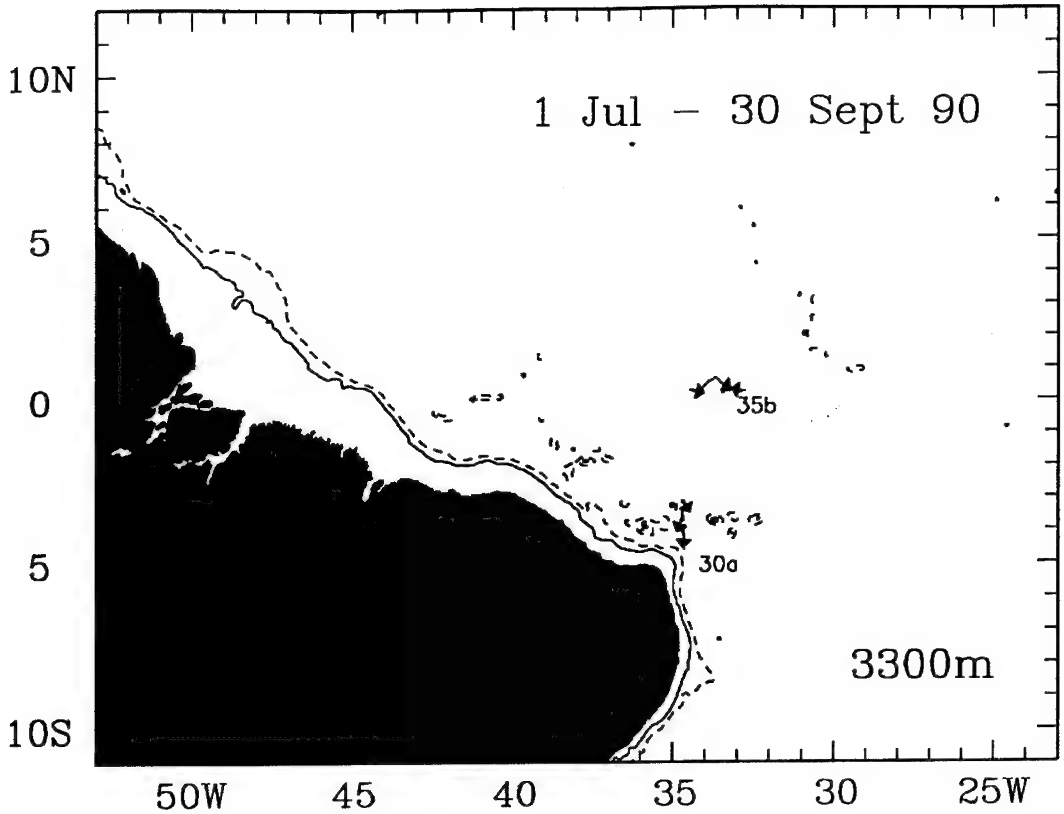

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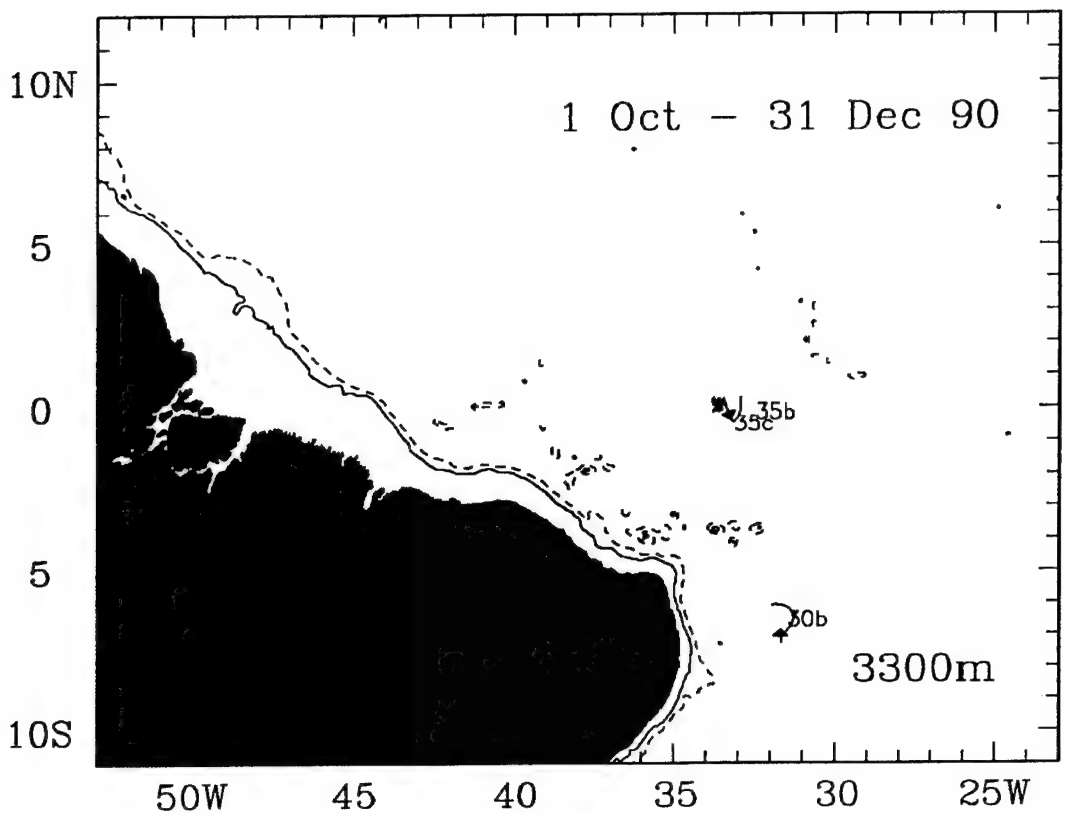

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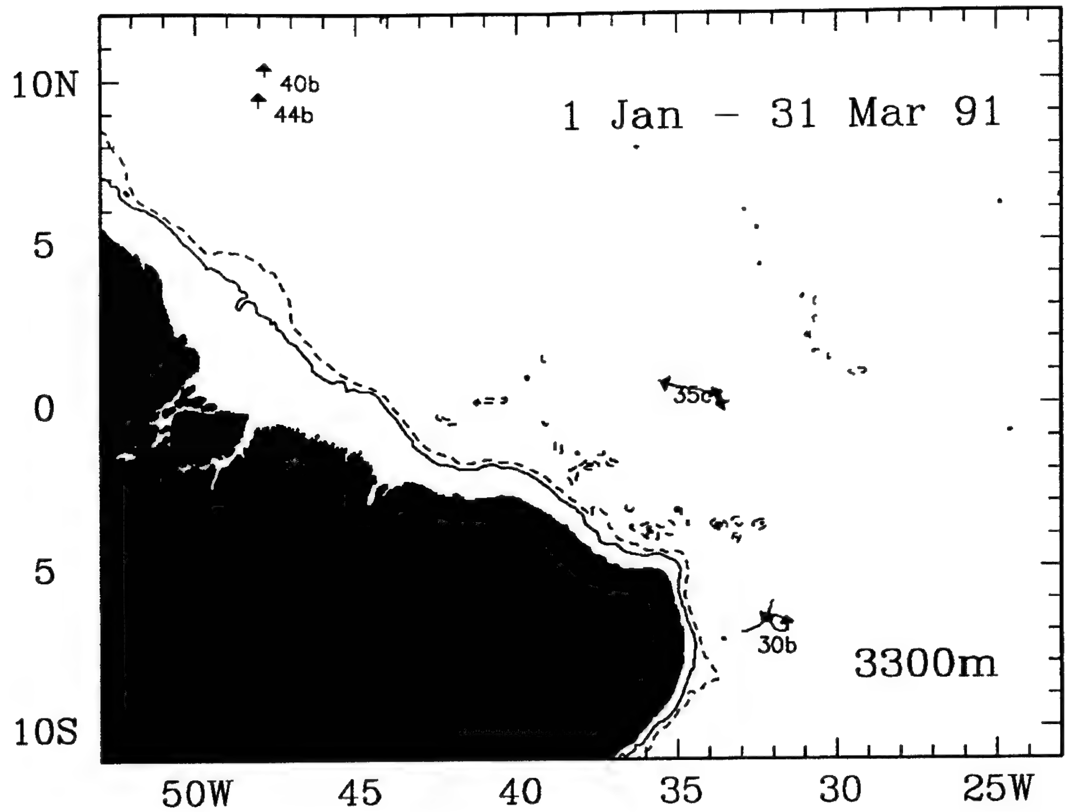

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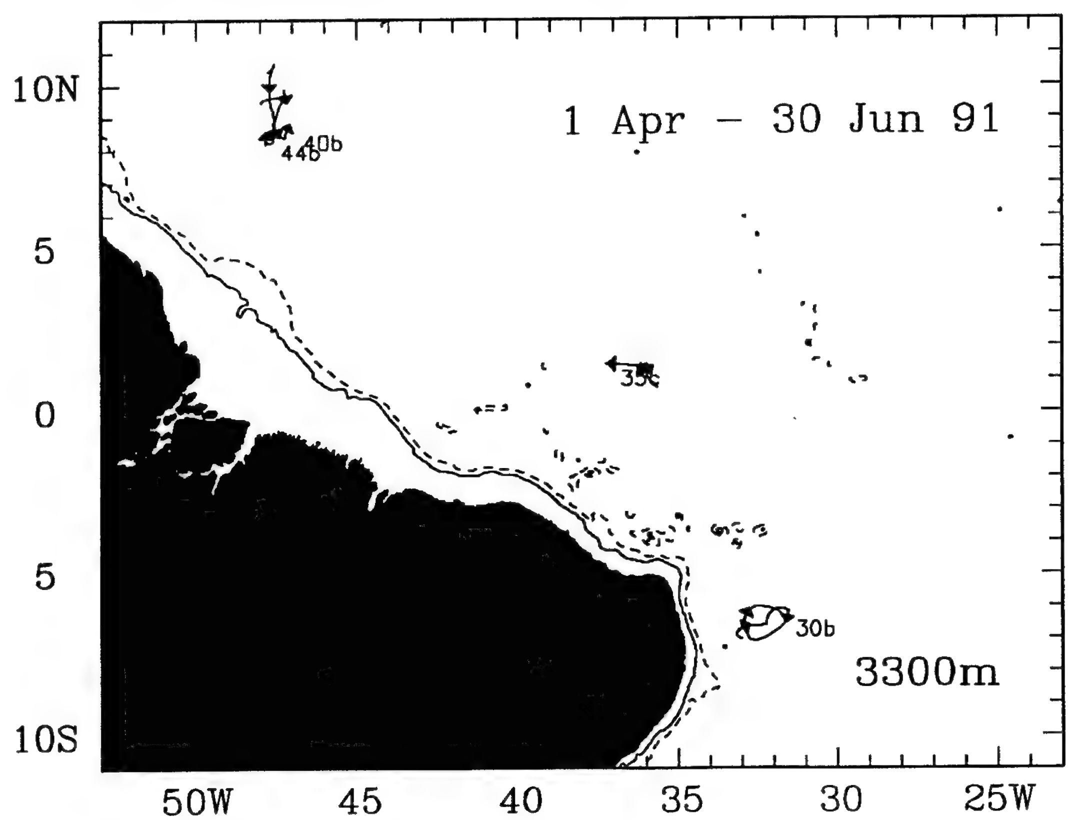
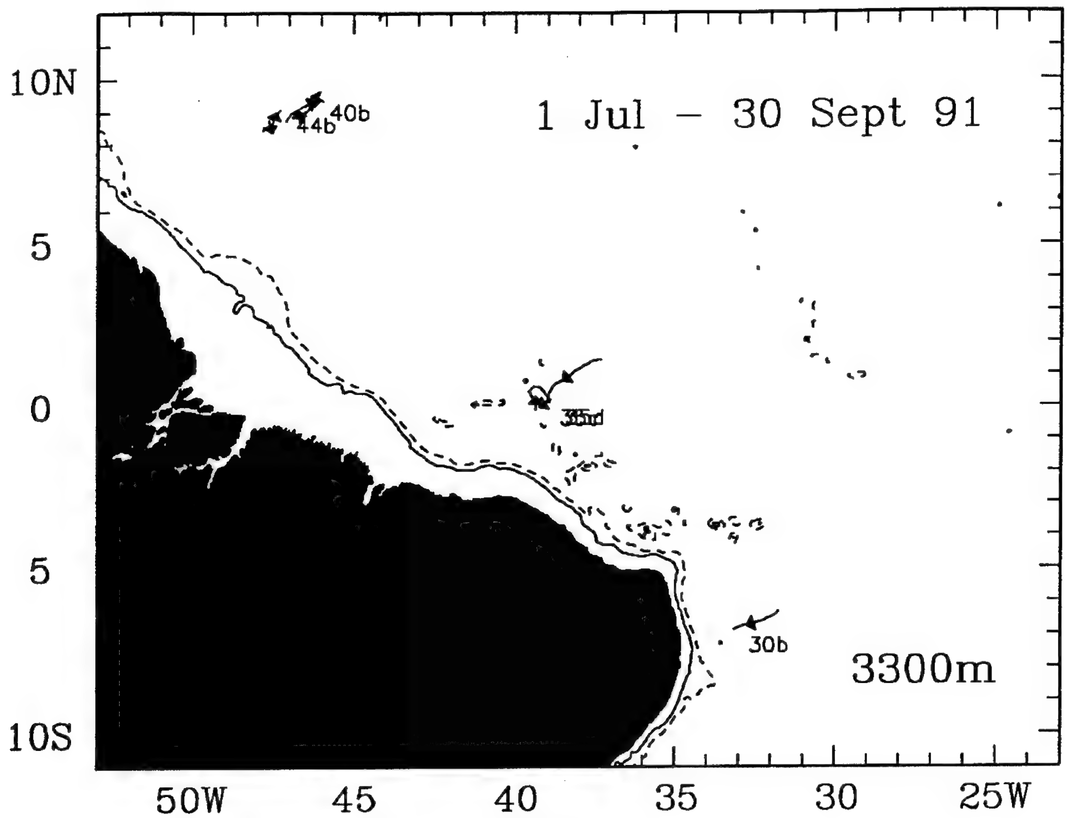
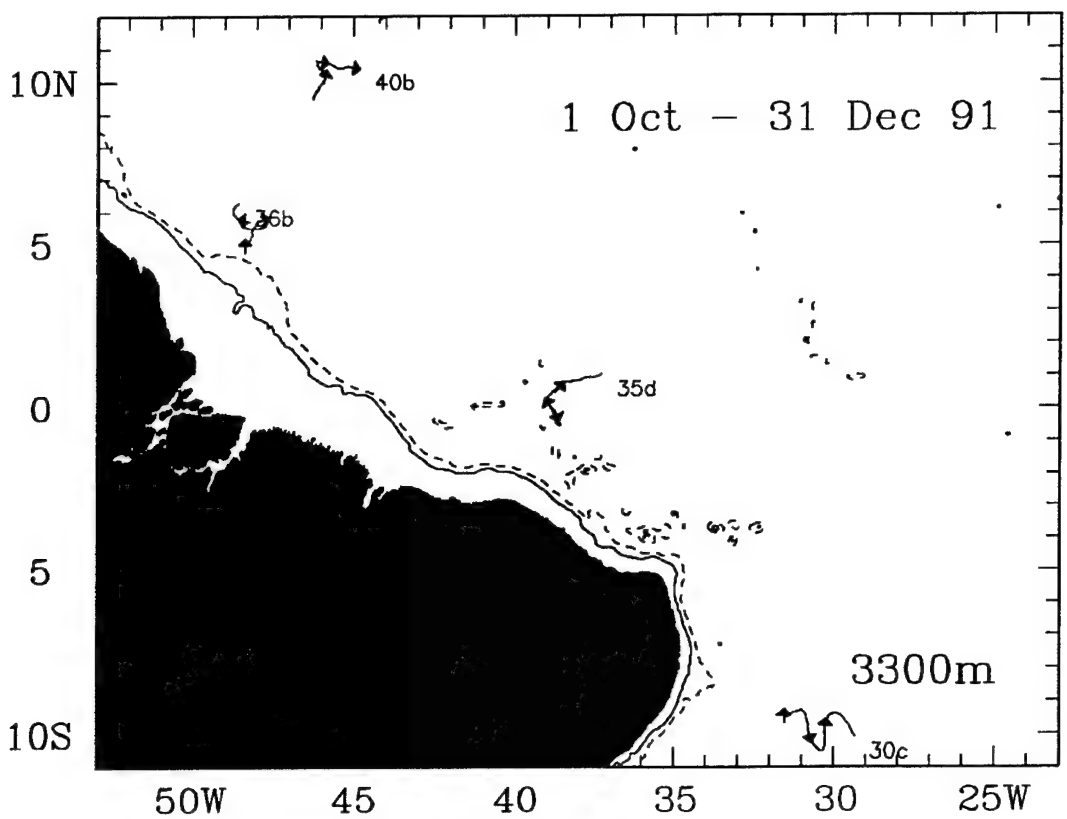
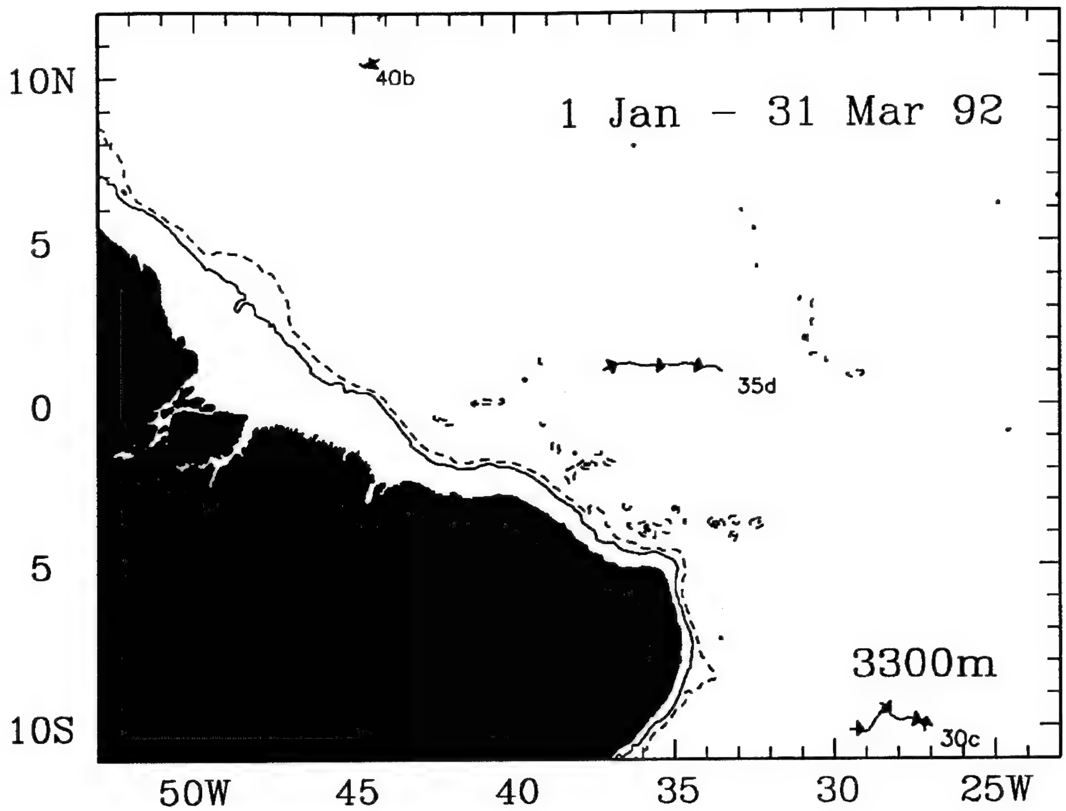
30b
3300m



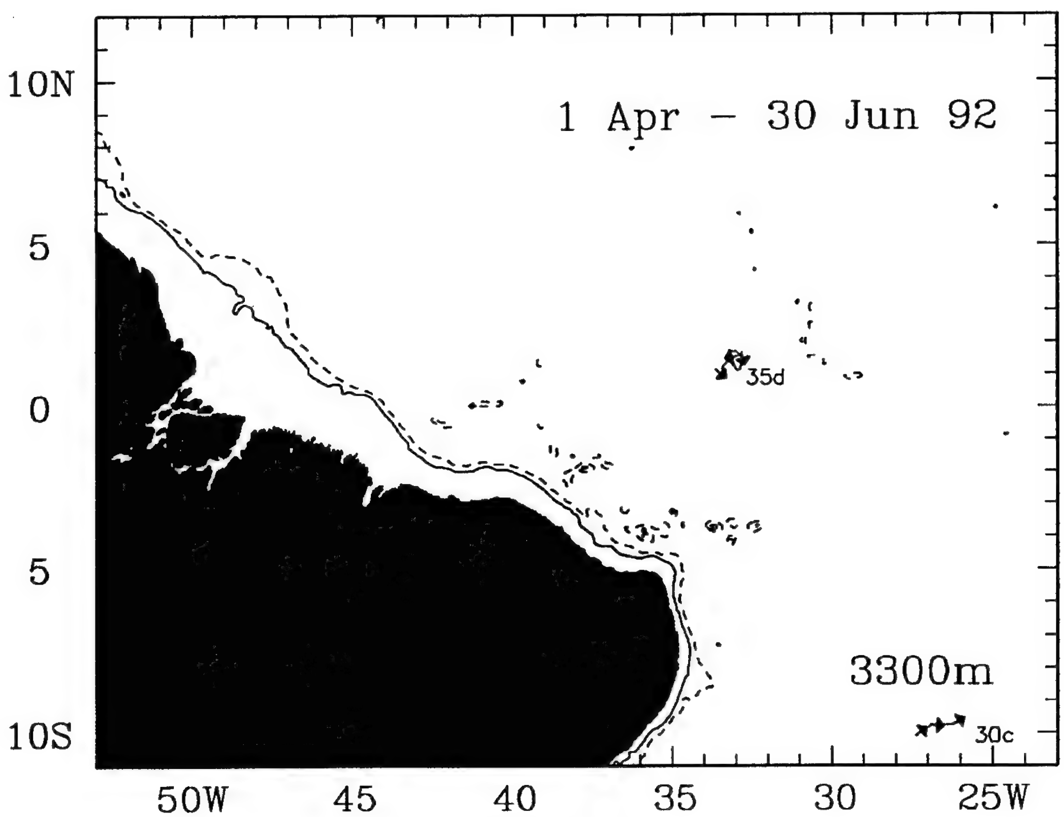
10N
5
0
5
10S
50W
45
40
35
30
25W
40b
44b
1 Apr – 30 Jun 91
35c
30b
3300m


1 Jul – 30 Sept 91
3300m
10N
5
0
5
10S
50W
45
40
35
30
25W
44b
40b
35d
30b

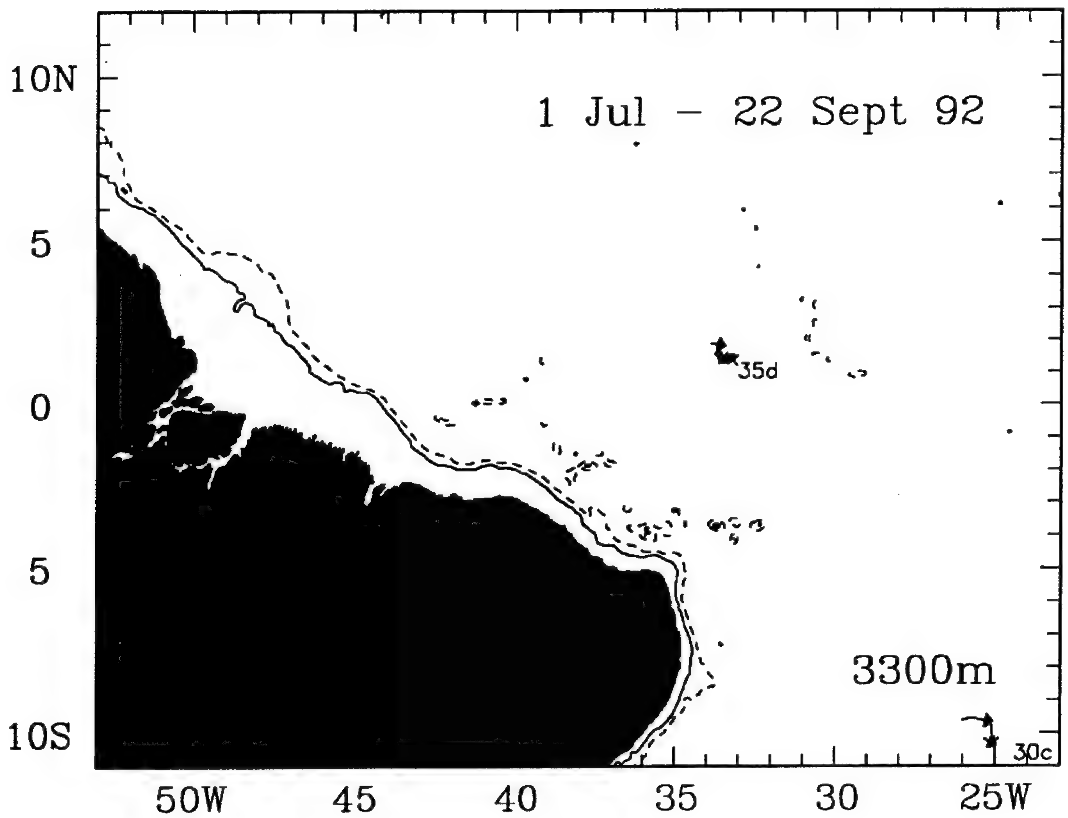

1 Oct – 31 Dec 91
3300m
10N
5
0
5
10S
50W
45
40
35
30
25W
40b
36b
35d
30c



10N
5
0
5
10S
50W
45
40
35
30
25W
1 Jan – 31 Mar 92
40b
35d
30c
3300m



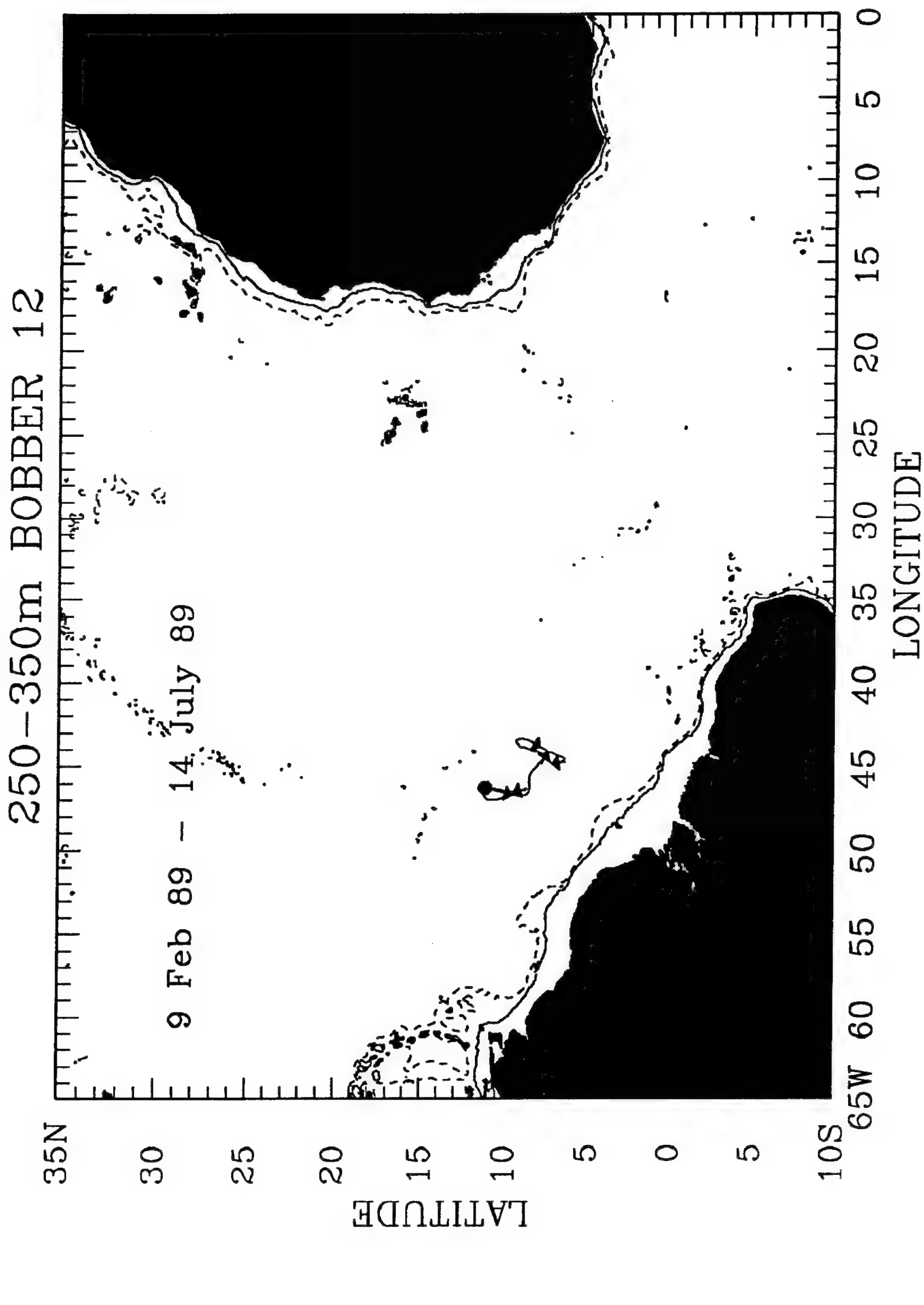
10N
5
0
5
10S
50W
45
40
35
30
25W
1 Apr – 30 Jun 92
35d
30c
3300m

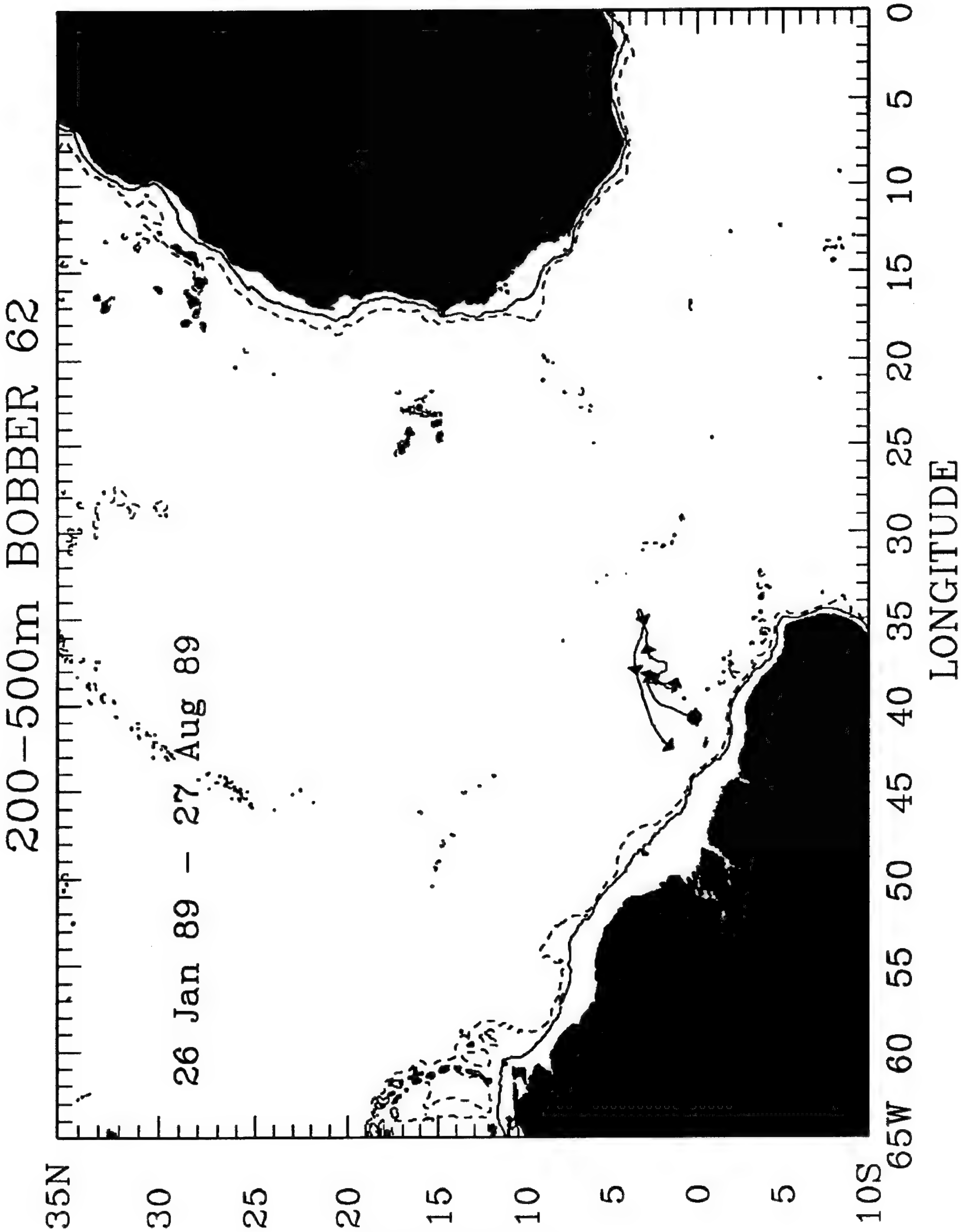


1 Jul - 22 Sept 92
10N
5
0
5
10S
50W
45
40
35
30
25W
35d
3300m
30c

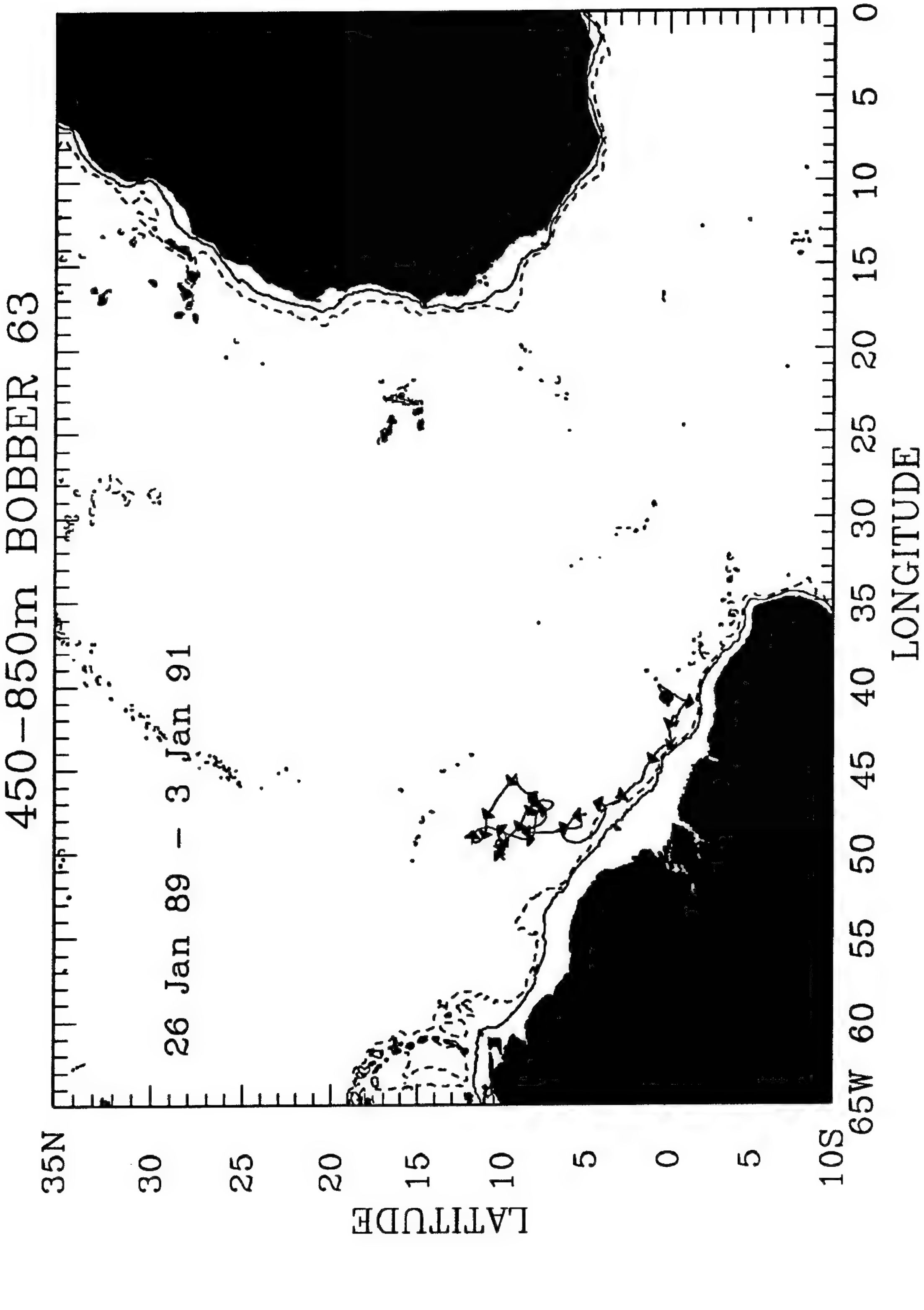
Appendix B: Plots of Individual Float Data

The following figures are ordered by increasing depth into four groups: (1) Bobbers, (2) 800 m floats, (3) 1800 m floats, and (4) 3300 m floats. Three plots are included for each float. The first is a common-area plot of the whole trajectory for the whole period January 1989 to September 1992 with arrowheads spaced at intervals of 30 days. The second and third figures are a trajectory enlargement showing daily positions and dates every 30 days and a time series of velocity vectors and eastward and northward velocity components for the second ALS deployment, October 1990–September 1992. Maximum and minimum pressures are added for Bobber floats. There are no figures in the second and third groups for floats that did not survive until the second ALS deployment. The 200 m depth contour is shown as a solid line; the 2000 m contour is dashed. The 4000 m contour was added as a solid line to the figures showing 3300 m floats.

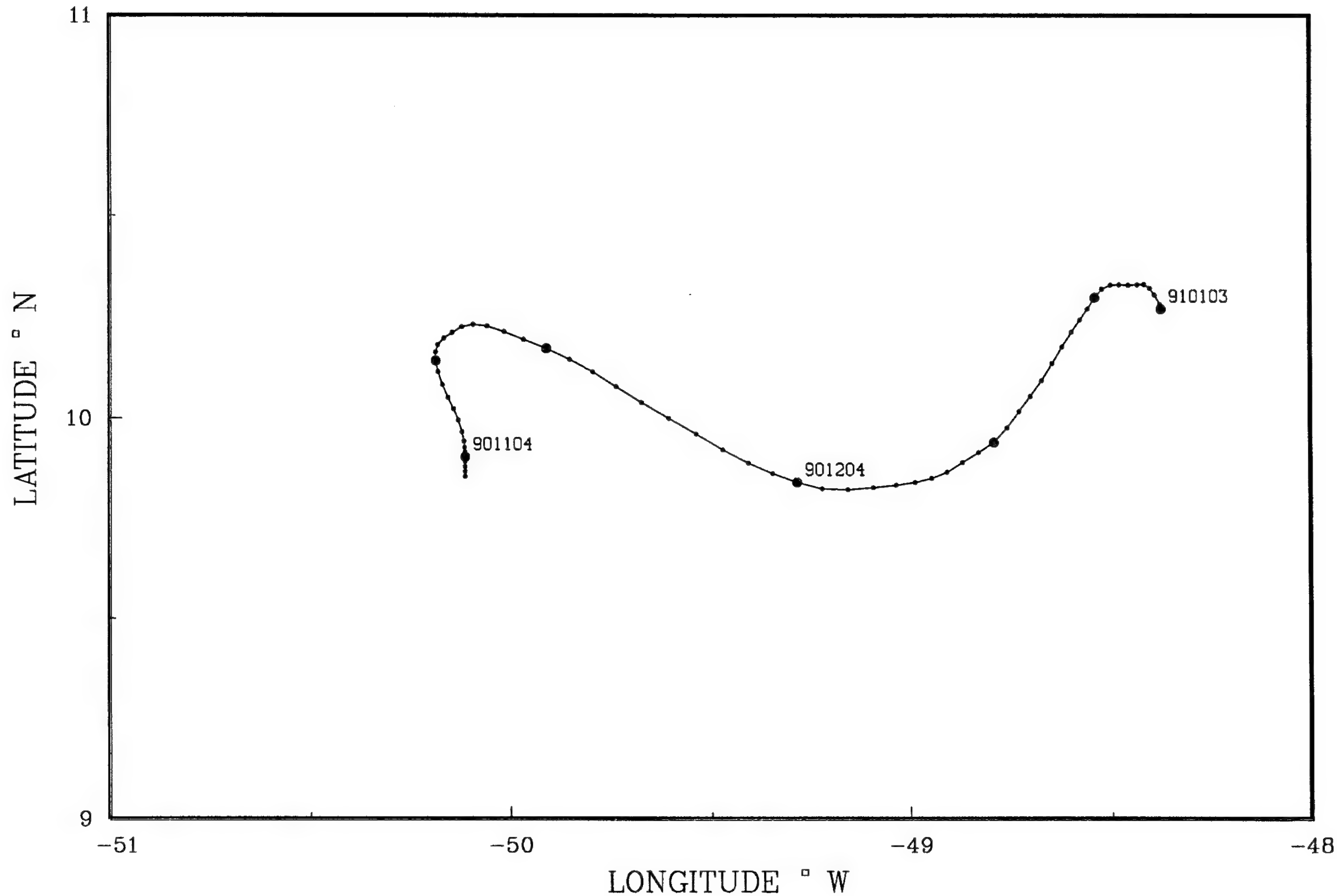

250–350m BOBBER 12
9 Feb 89 – 14 July 89
LONGITUDE
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

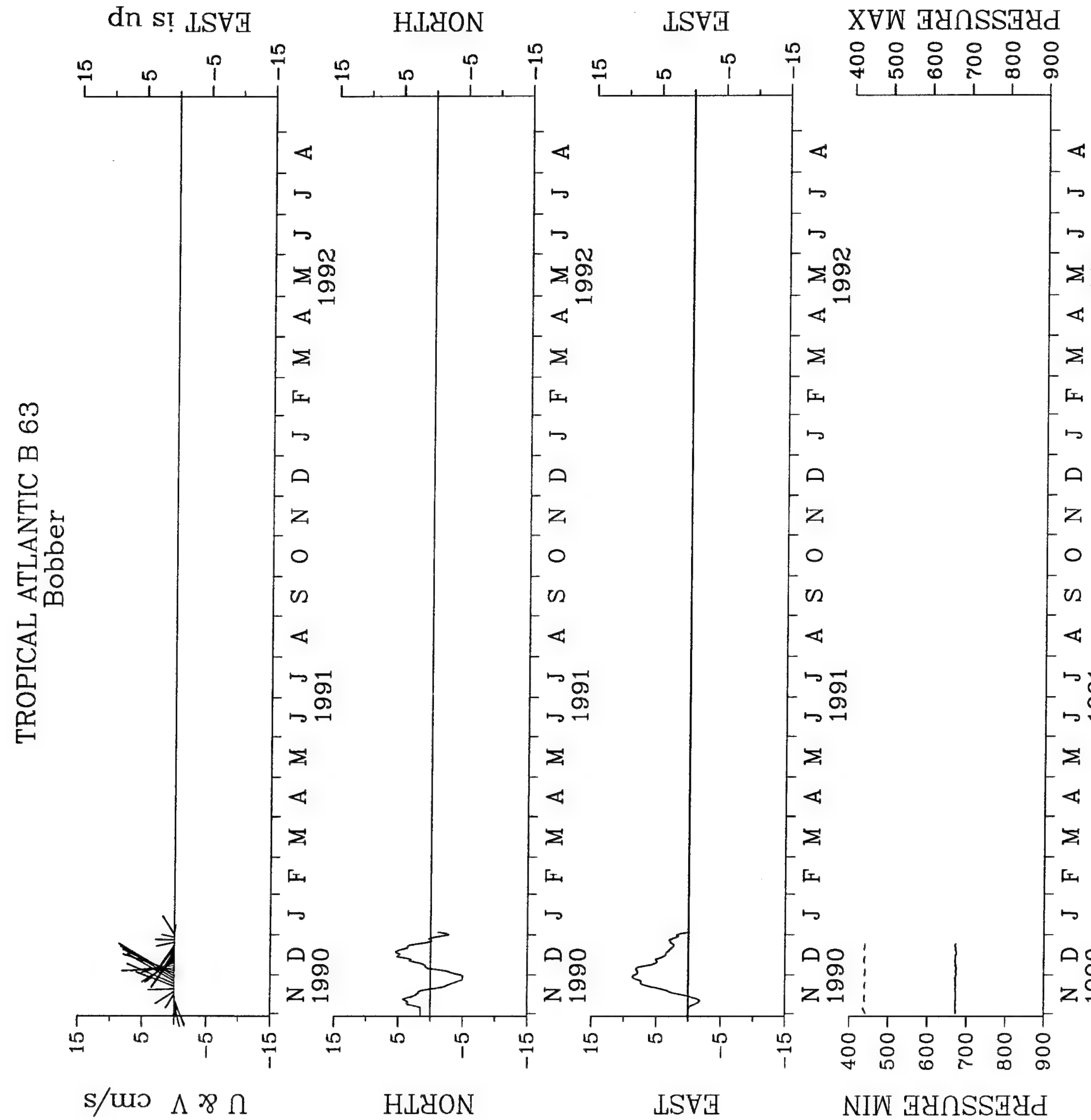


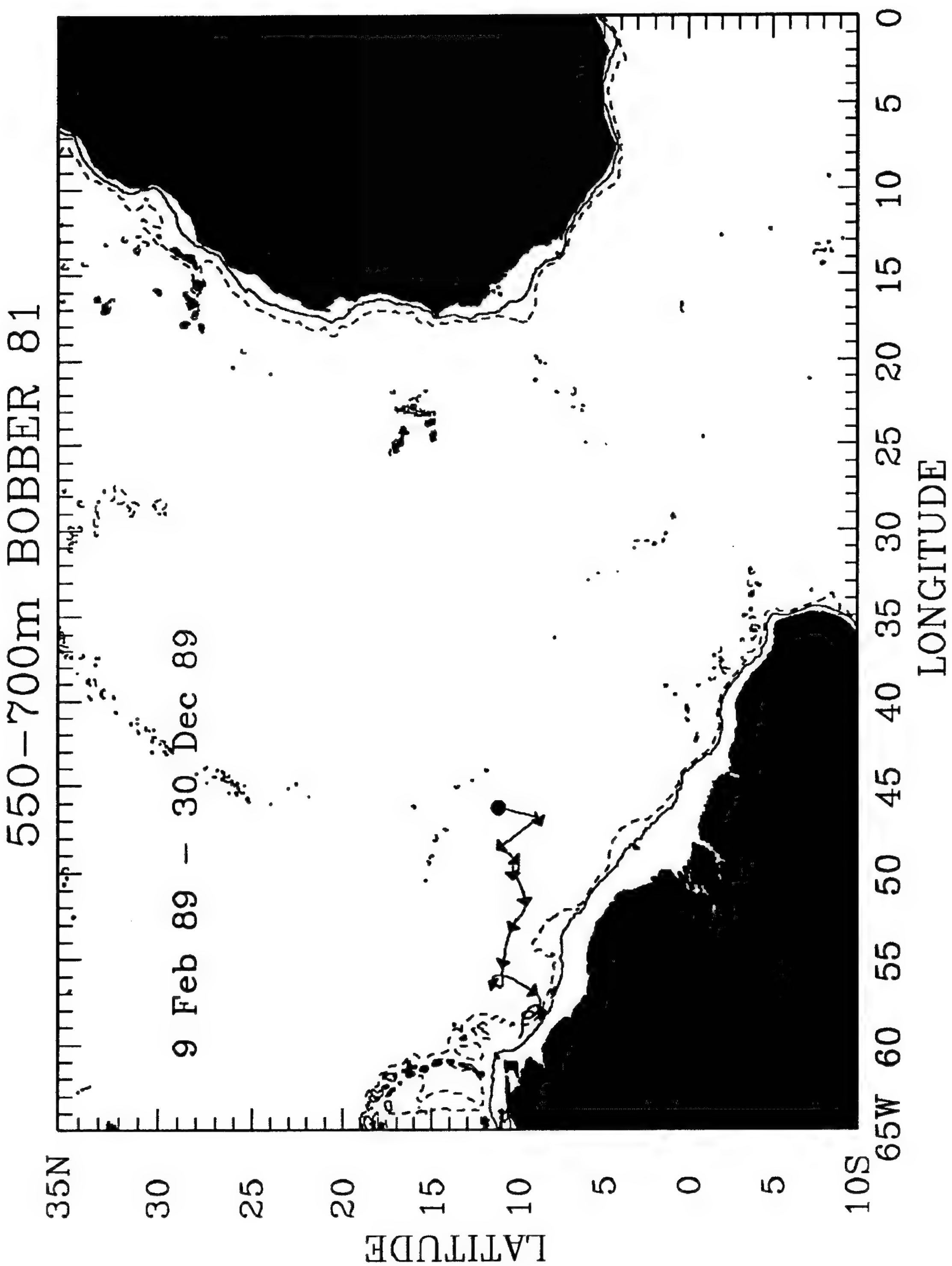
200–500m BOBBER 62
26 Jan 89 - 27 Aug 89
LONGITUDE
LATITUDE
65W 60 55 50 45 40 35 30 25 20 15 10 5 0
35N 30 25 20 15 10 5 0 5 10S

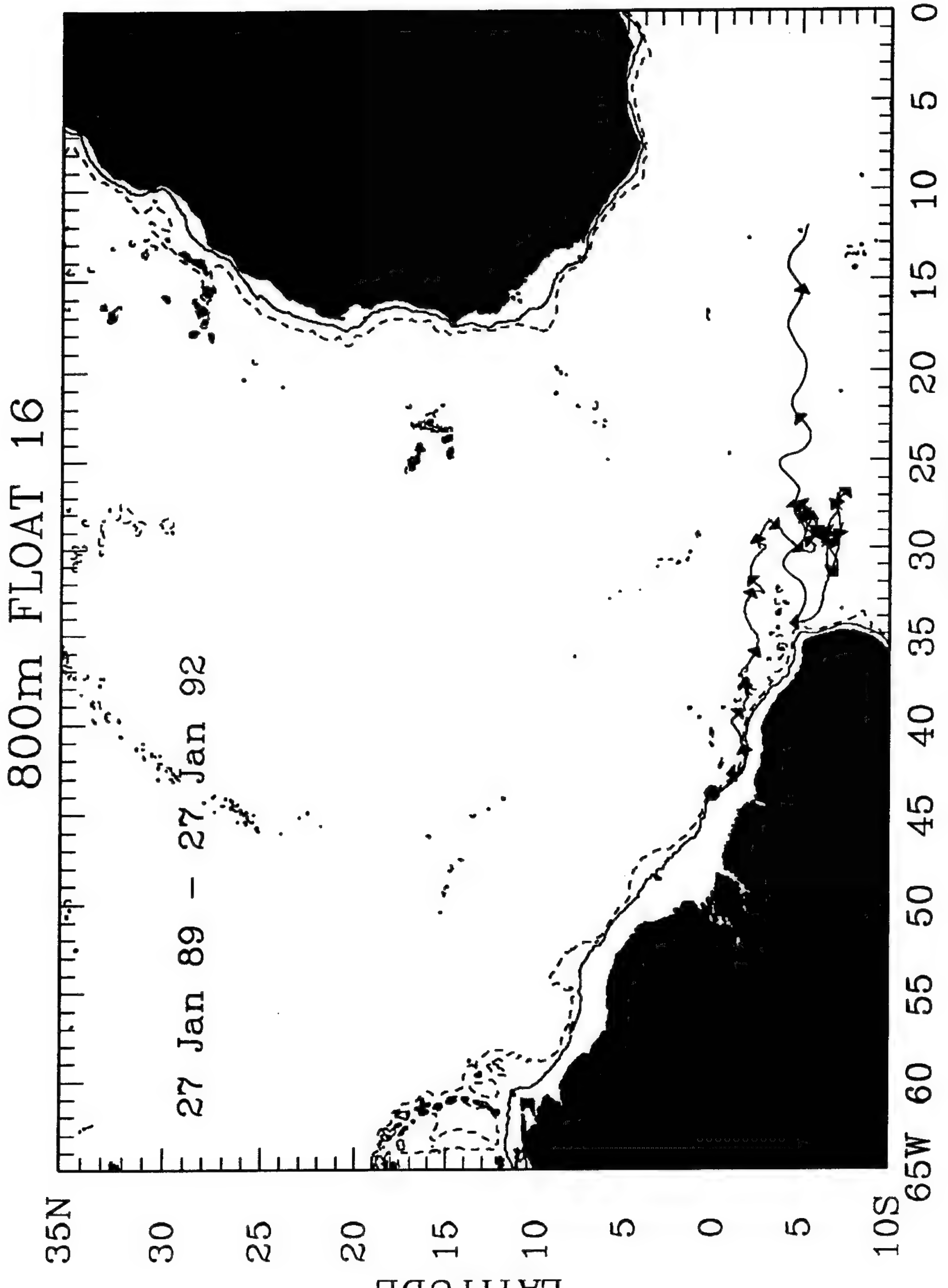

450–850m BOBBER 63
26 Jan 89 – 3 Jan 91
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

TROPICAL ATLANTIC B 63

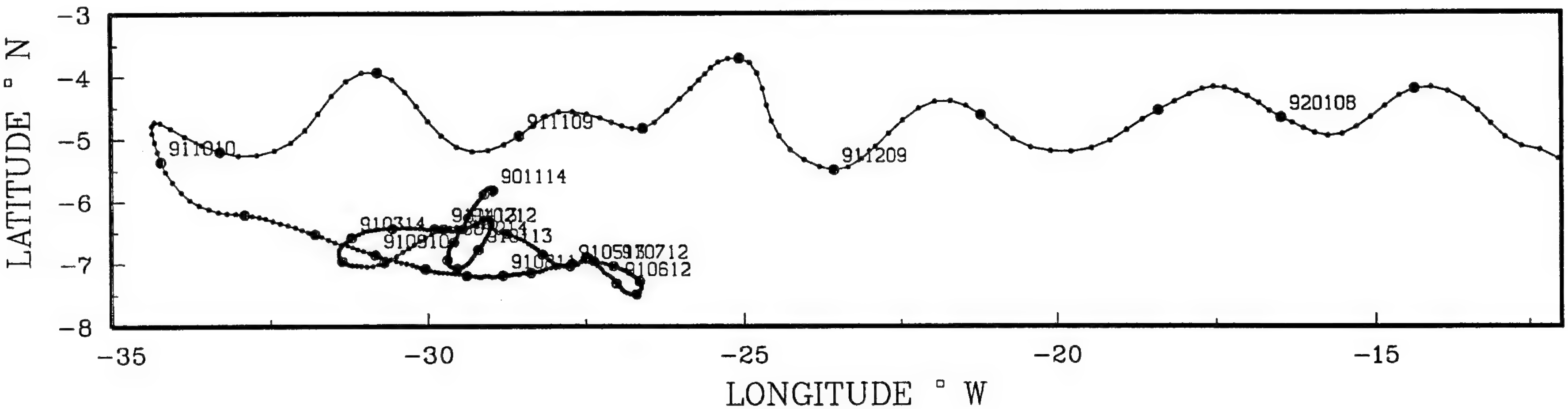



TROPICAL ATLANTIC B 63
Bobber
U & V cm/s
EAST is up
NORTH
EAST
PRESSURE MIN
PRESSURE MAX
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

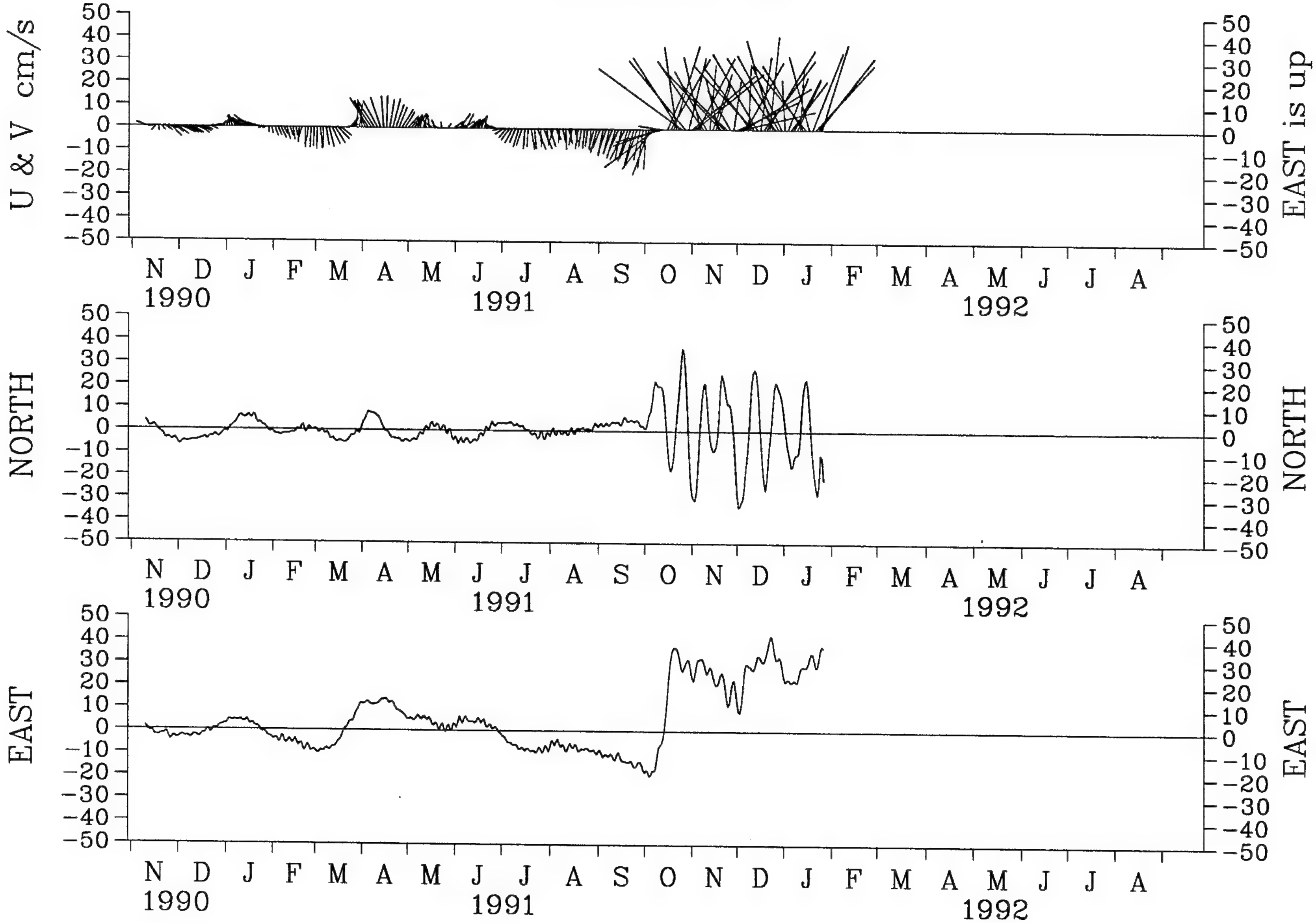

550–700m BOBBER 81
9 Feb 89 – 30 Dec 89
LONGITUDE
LATITUDE
65W 60 55 50 45 40 35 30 25 20 15 10 5 0
35N 30 25 20 15 10 5 0 5 10S

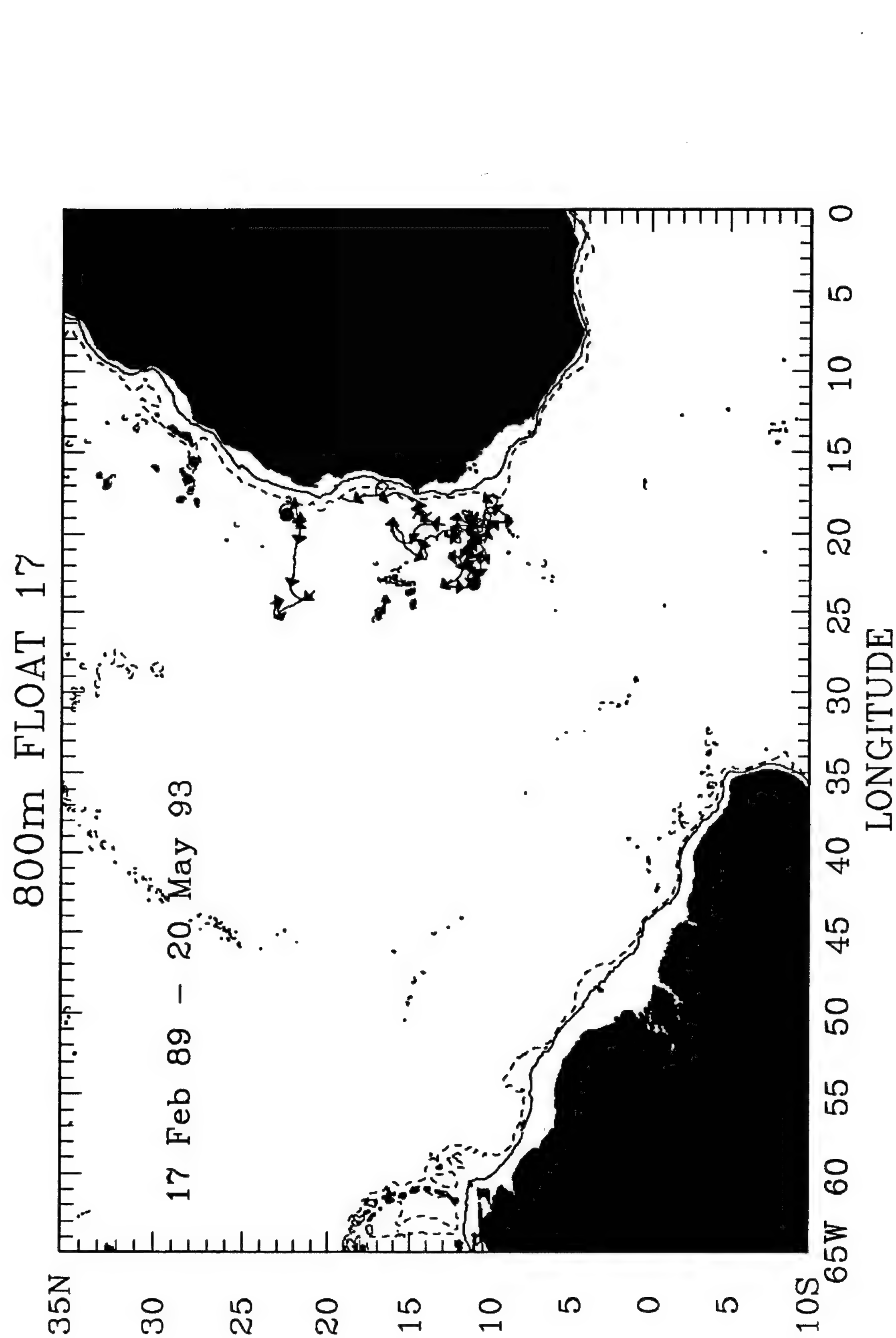

800m FLOAT 16
27 Jan 89 - 27 Jan 92
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

TROPICAL ATLANTIC 16



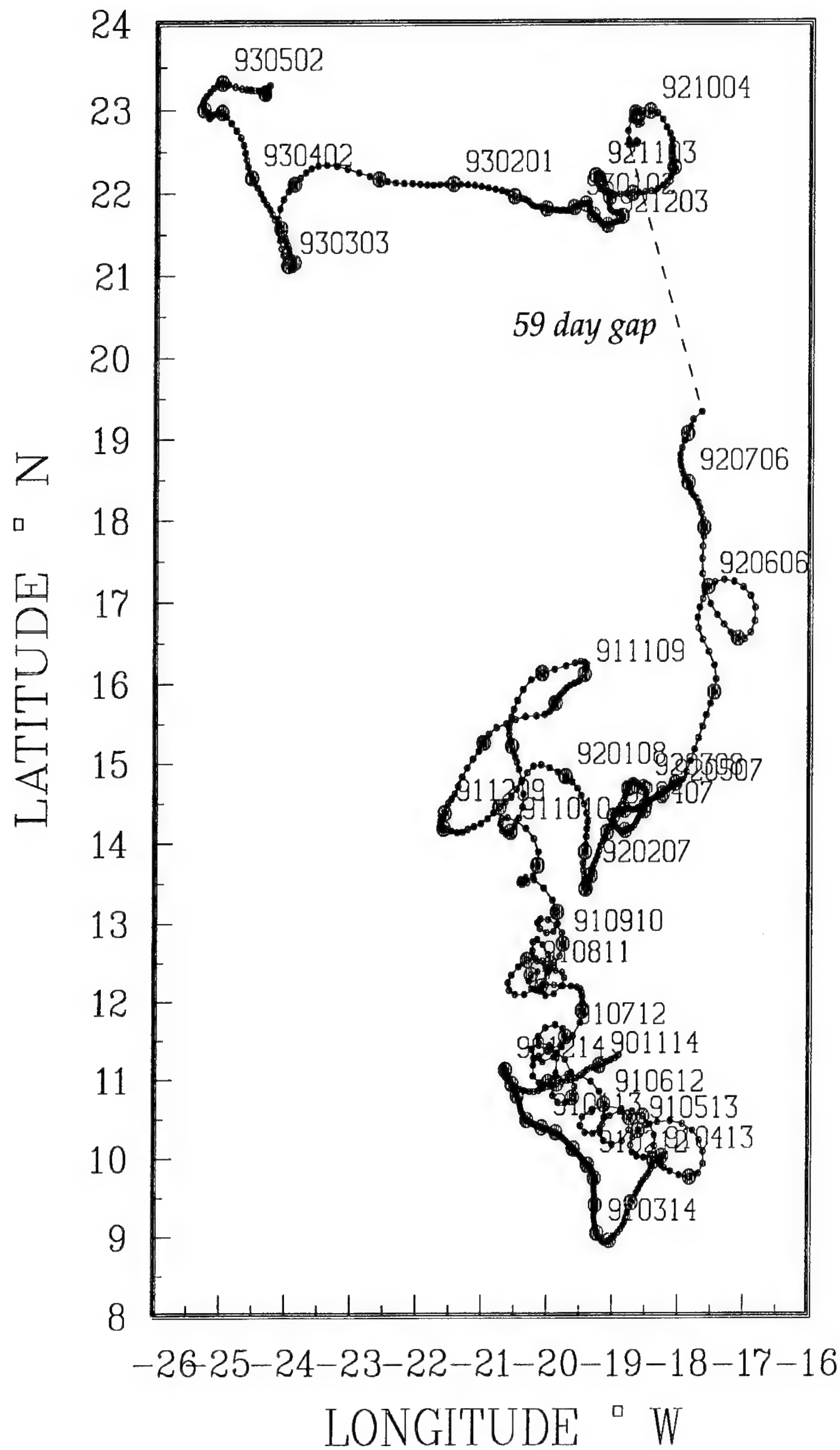
TROPICAL ATLANTIC 16
DEPTH 800 m.



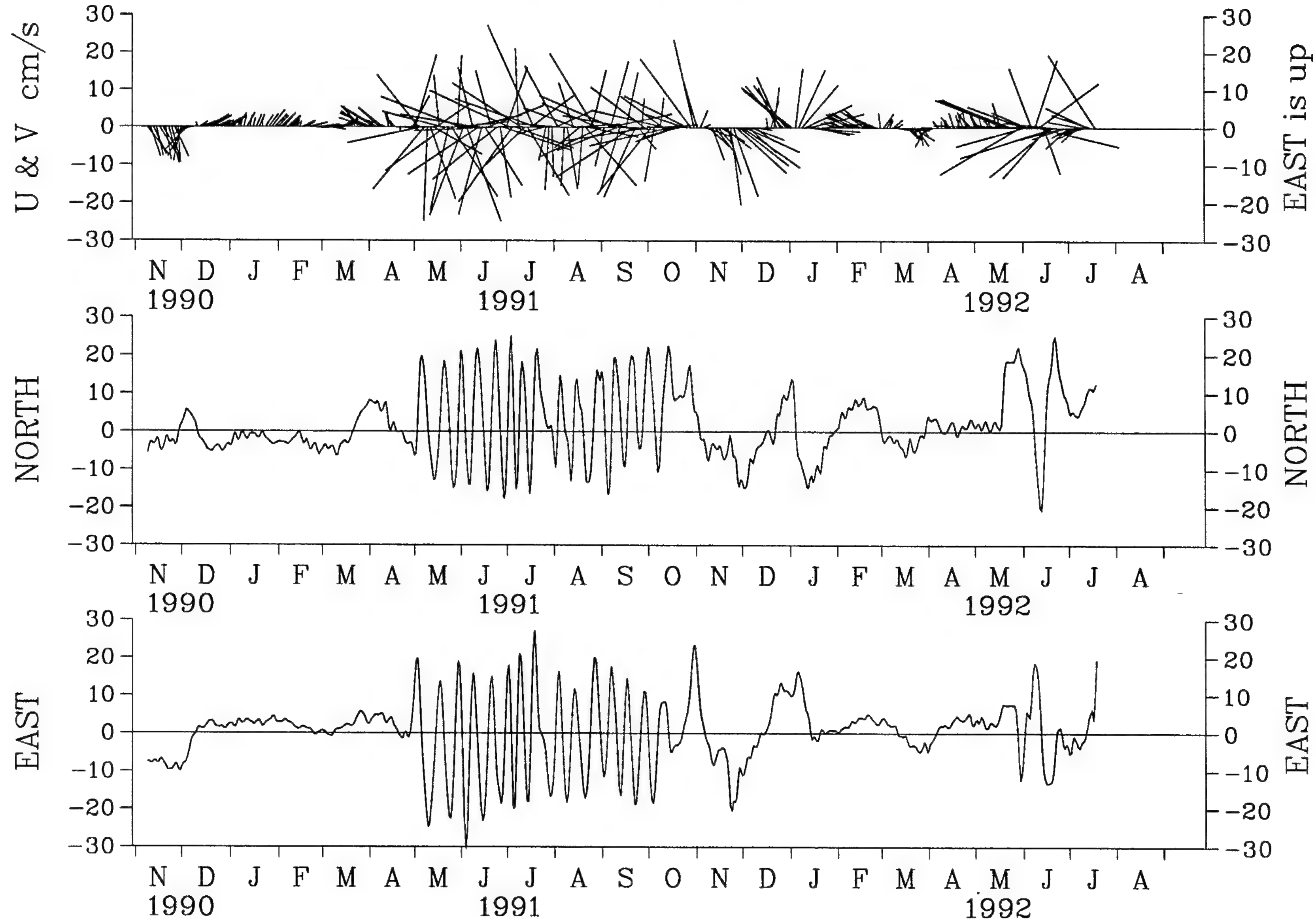


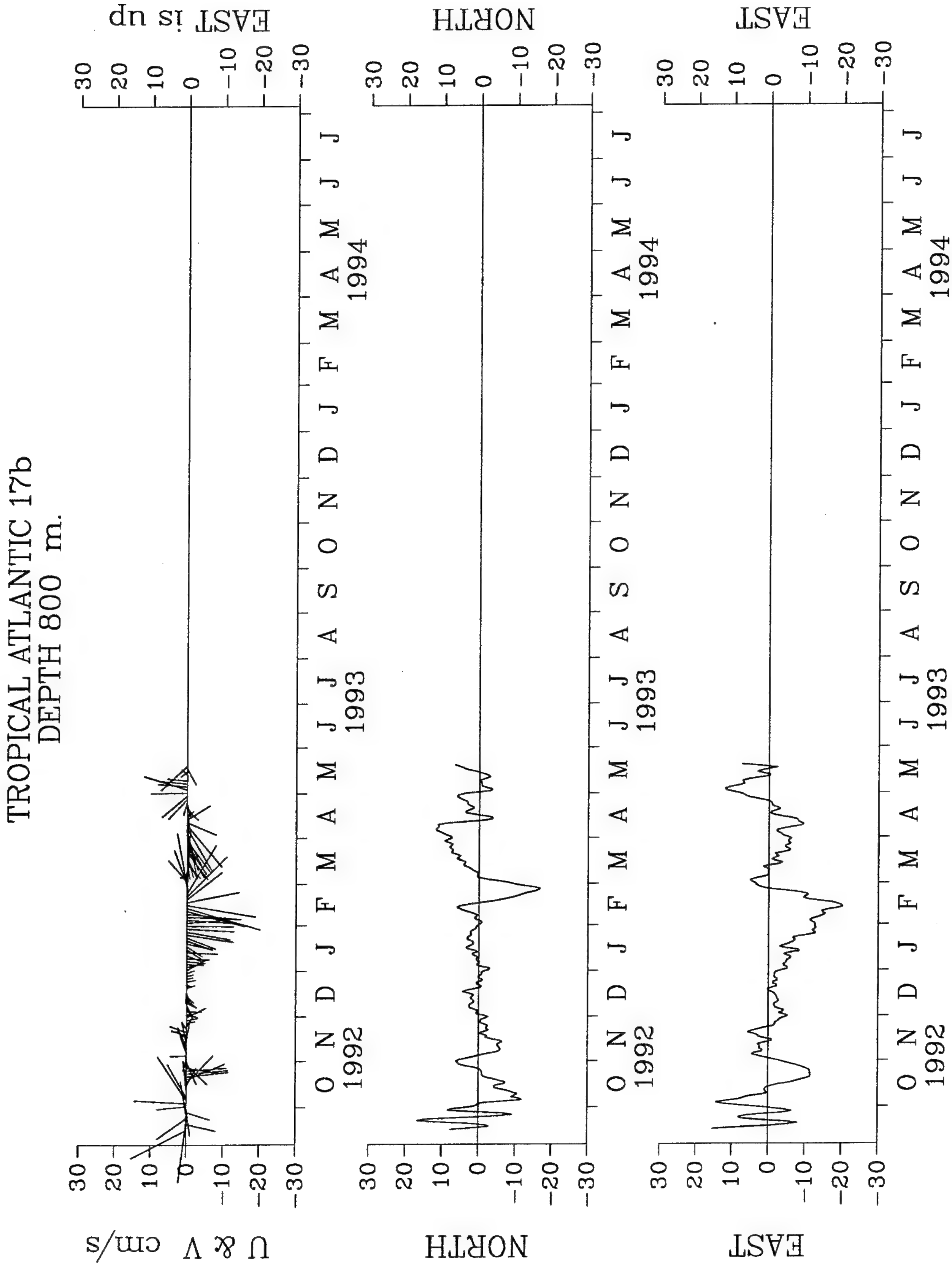
800m FLOAT 17
17 Feb 89 - 20 May 93
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

TROPICAL ATLANTIC 17

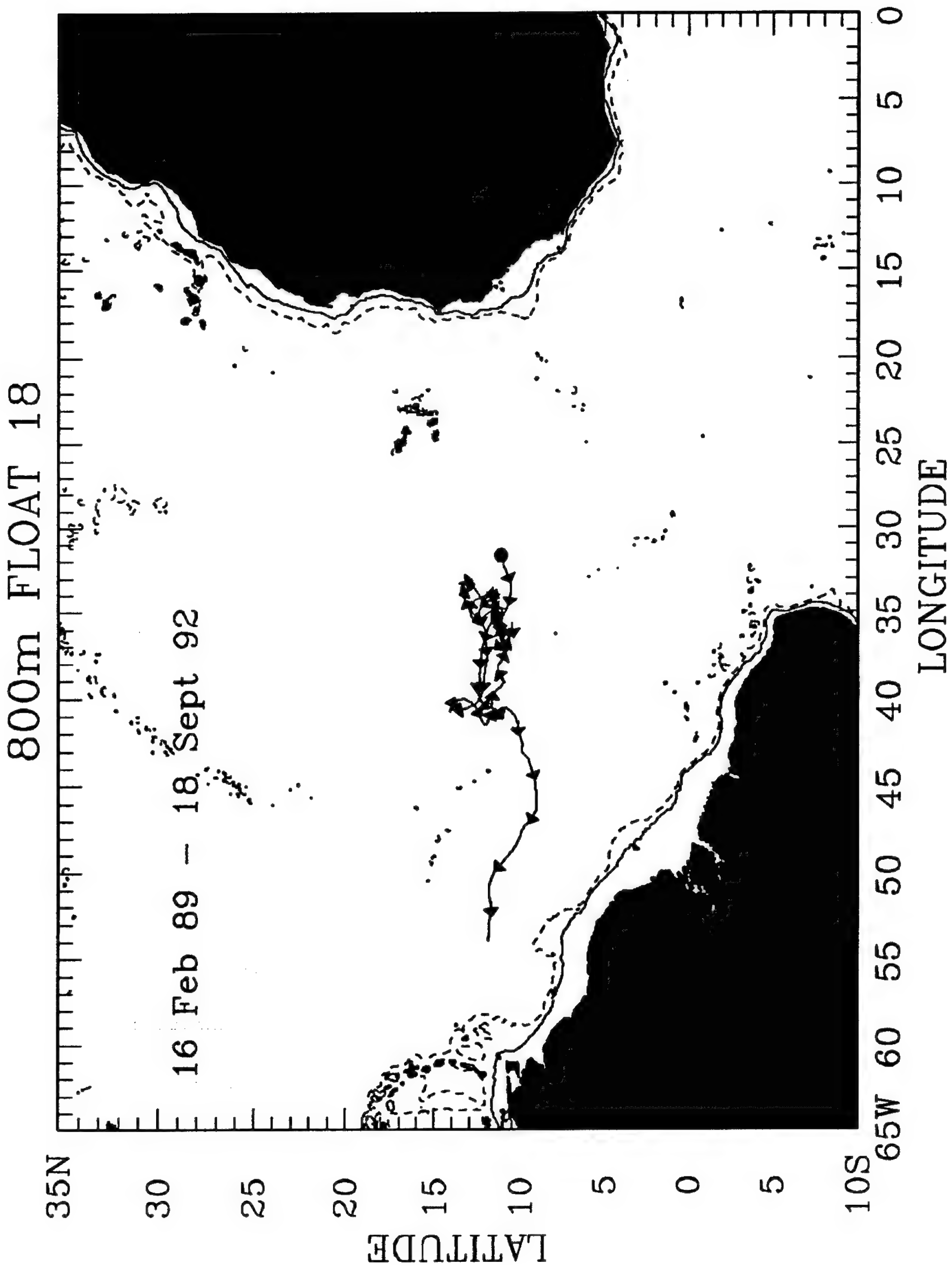


TROPICAL ATLANTIC 17a
DEPTH 800 m.

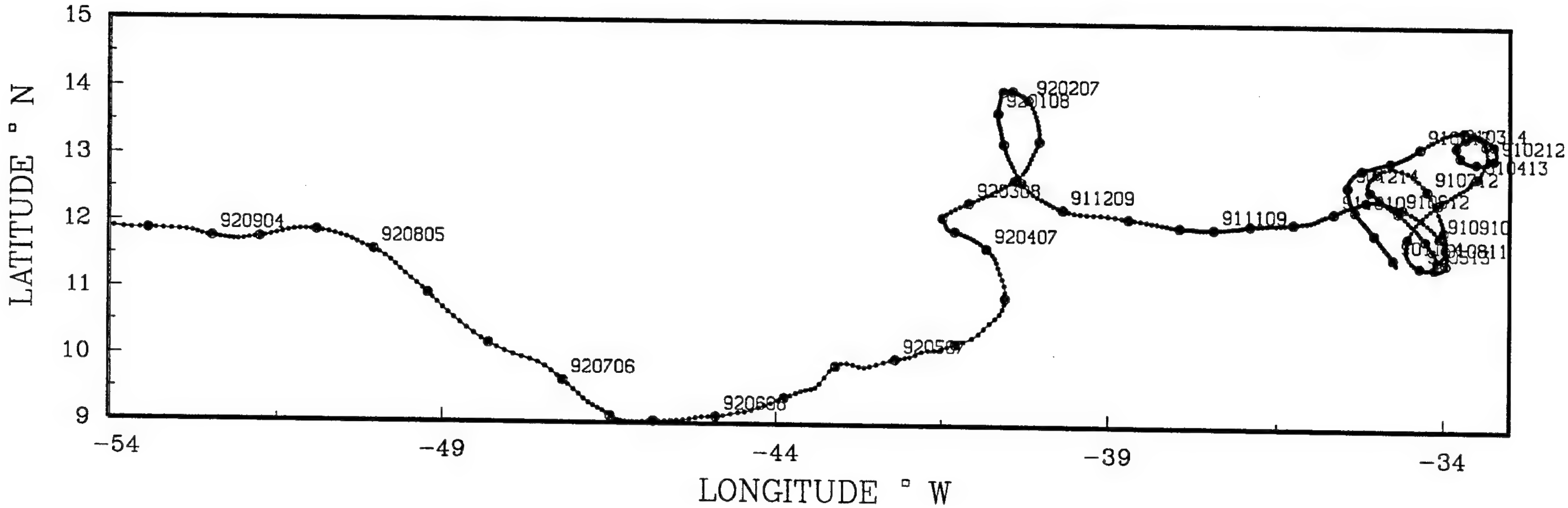


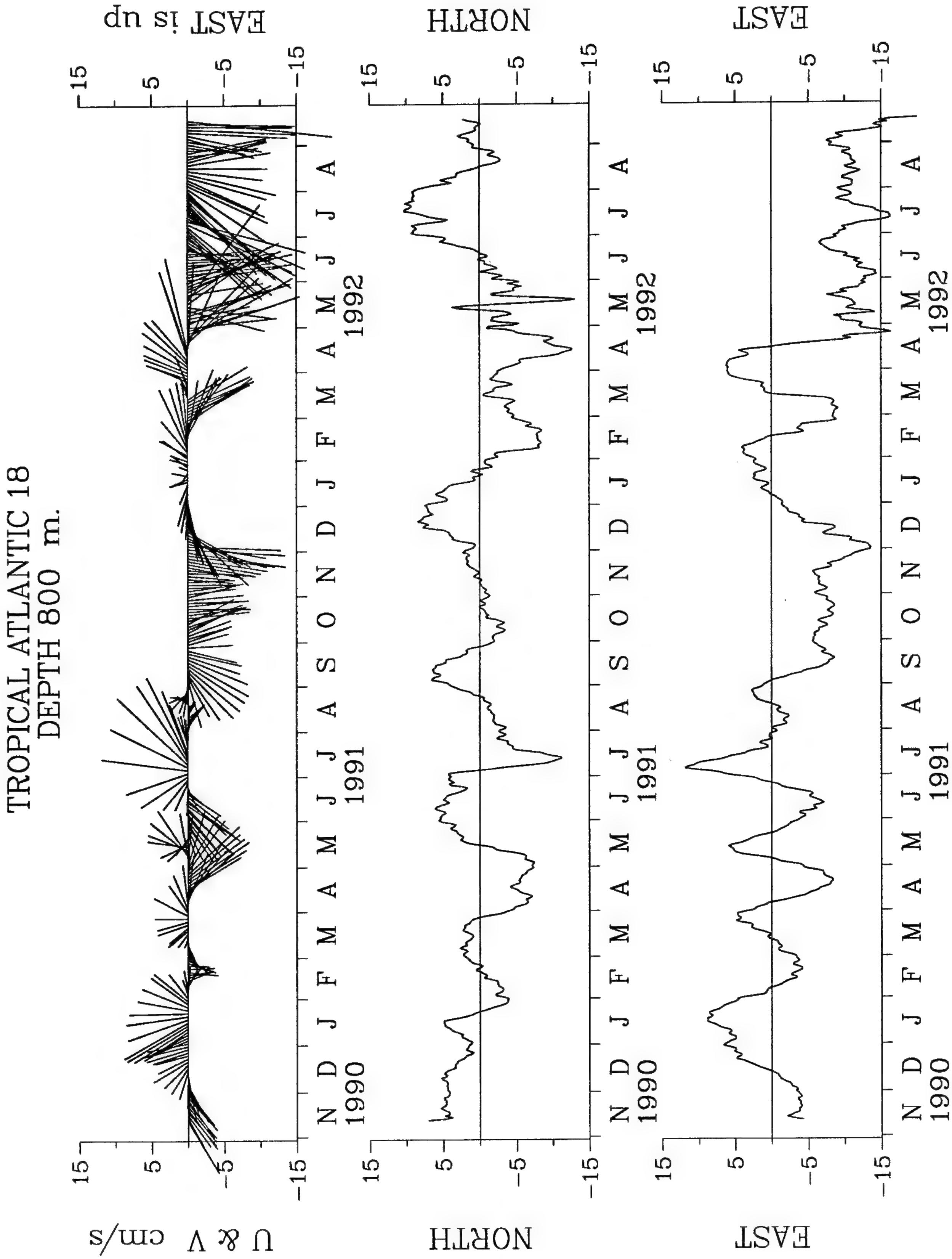


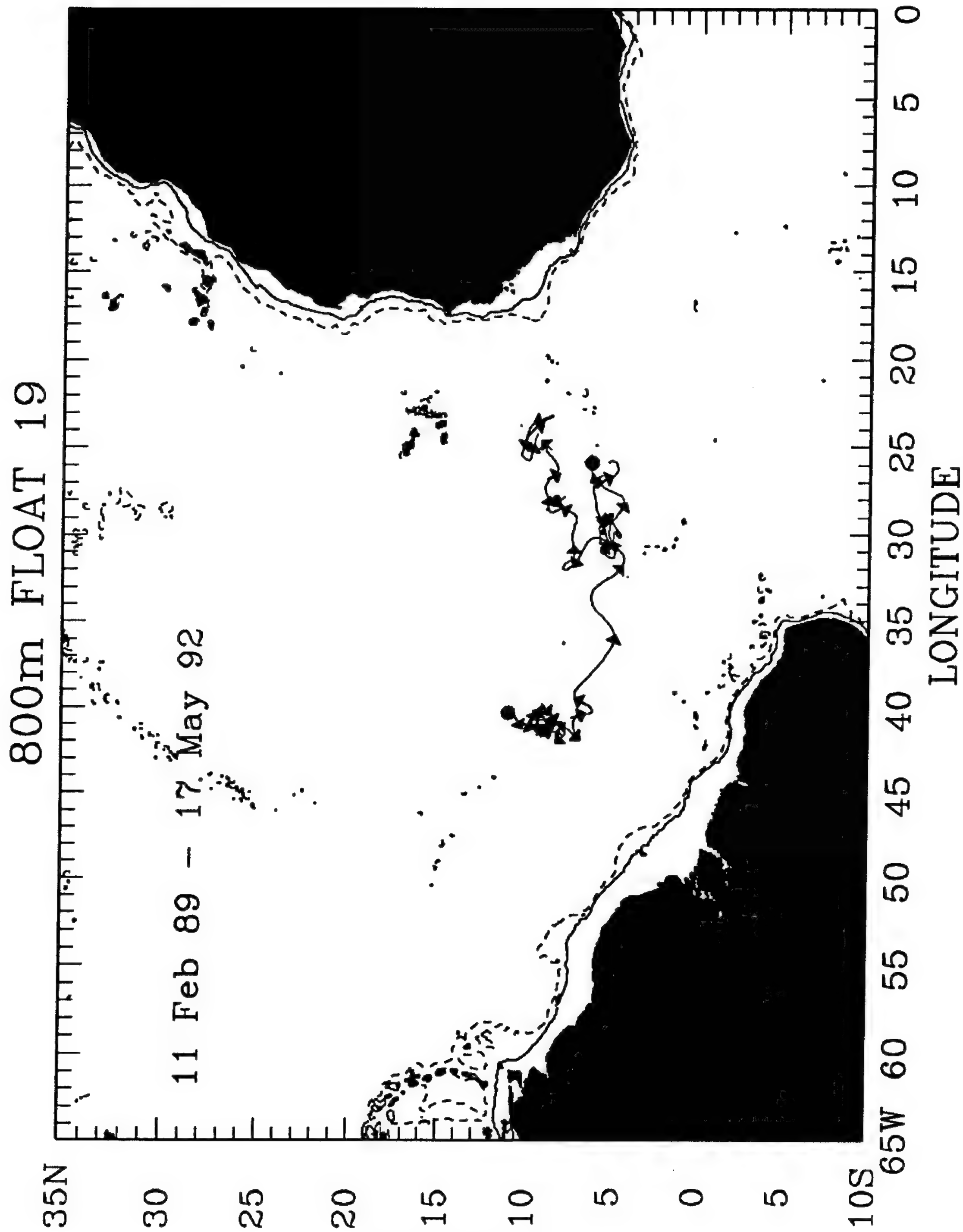
TROPICAL ATLANTIC 17b
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30
20
10
0
−10
−20
−30
O N D J F M A M J J A S O N D J F M A M J J
1992
1993
1994


800m FLOAT 18
16 Feb 89 – 18 Sept 92
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

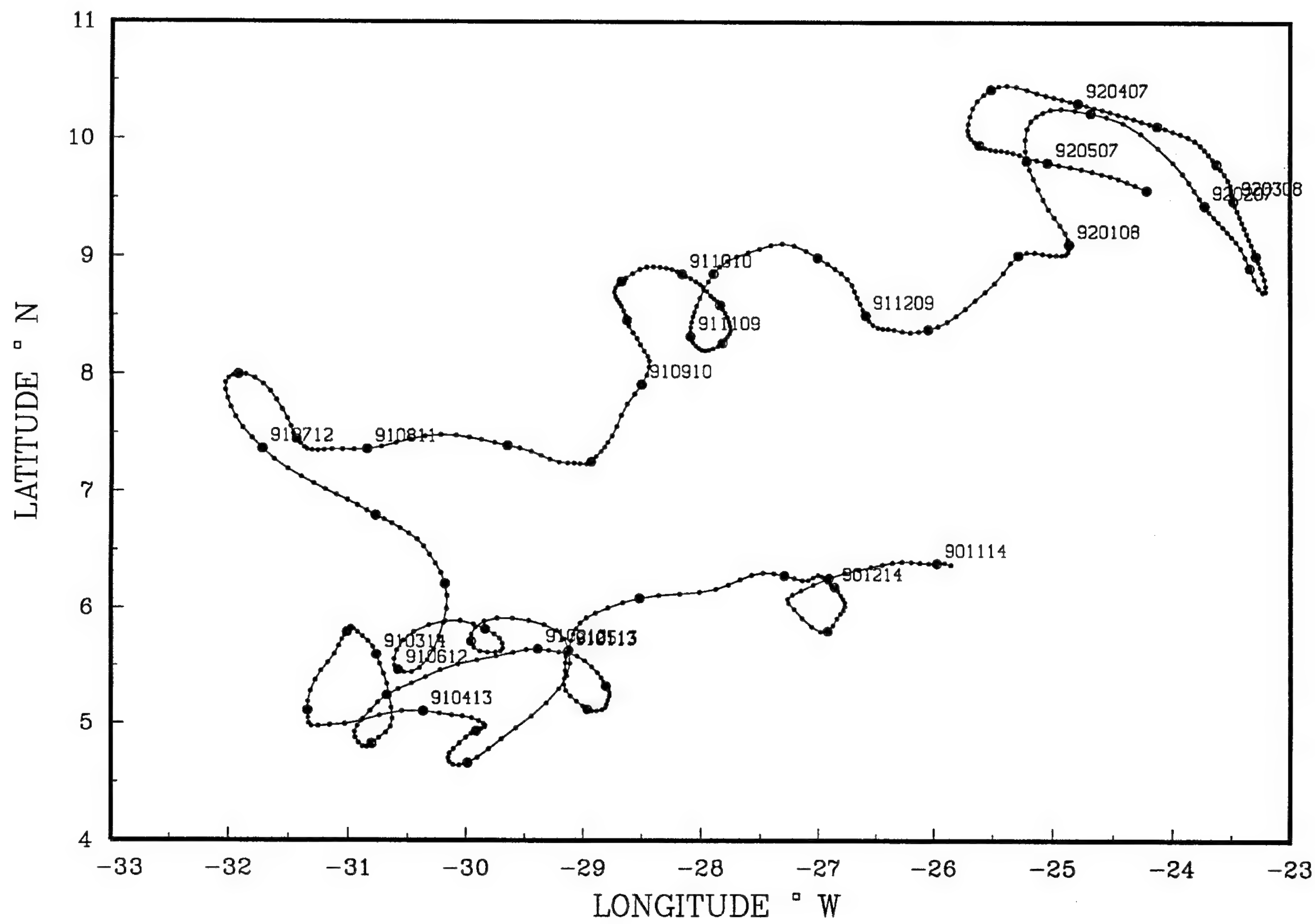
TROPICAL ATLANTIC 18

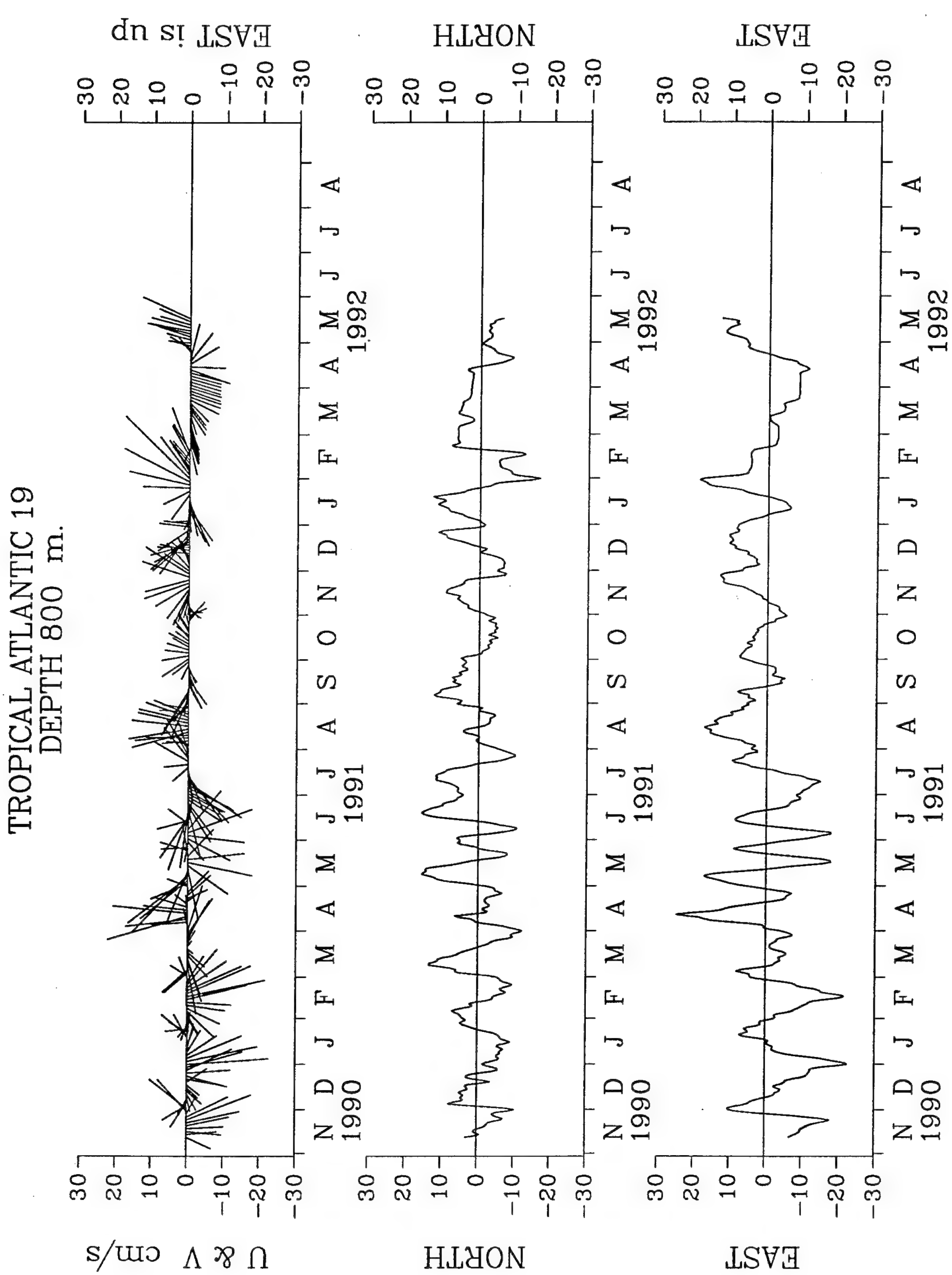



TROPICAL ATLANTIC 18
DEPTH 800 m.
EAST is up
U & V cm/s
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

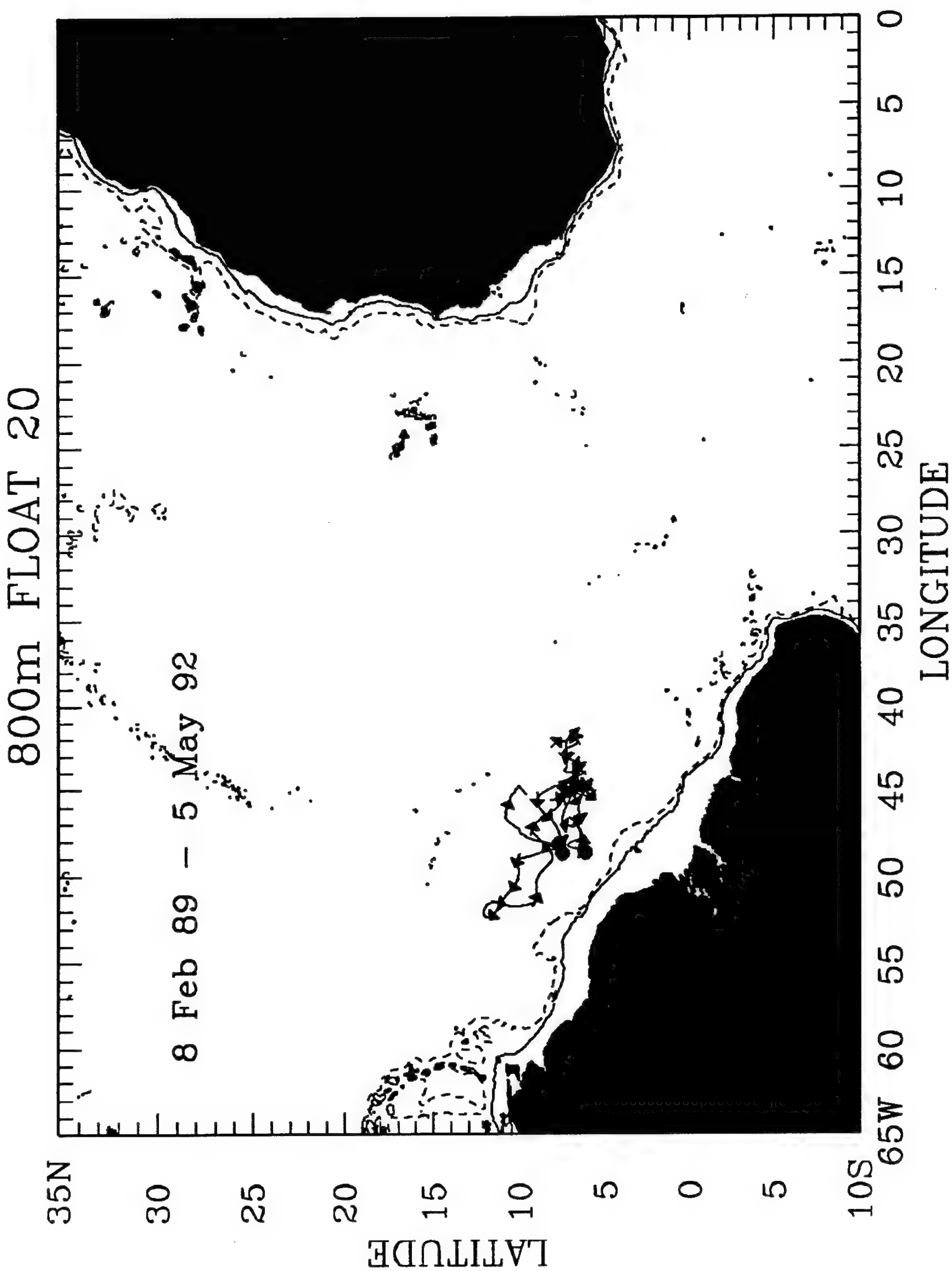

800m FLOAT 19
11 Feb 89 - 17 May 92
LONGITUDE
LATITUDE
65W 60 55 50 45 40 35 30 25 20 15 10 5 0
35N 30 25 20 15 10 5 0 5 10S

TROPICAL ATLANTIC 19

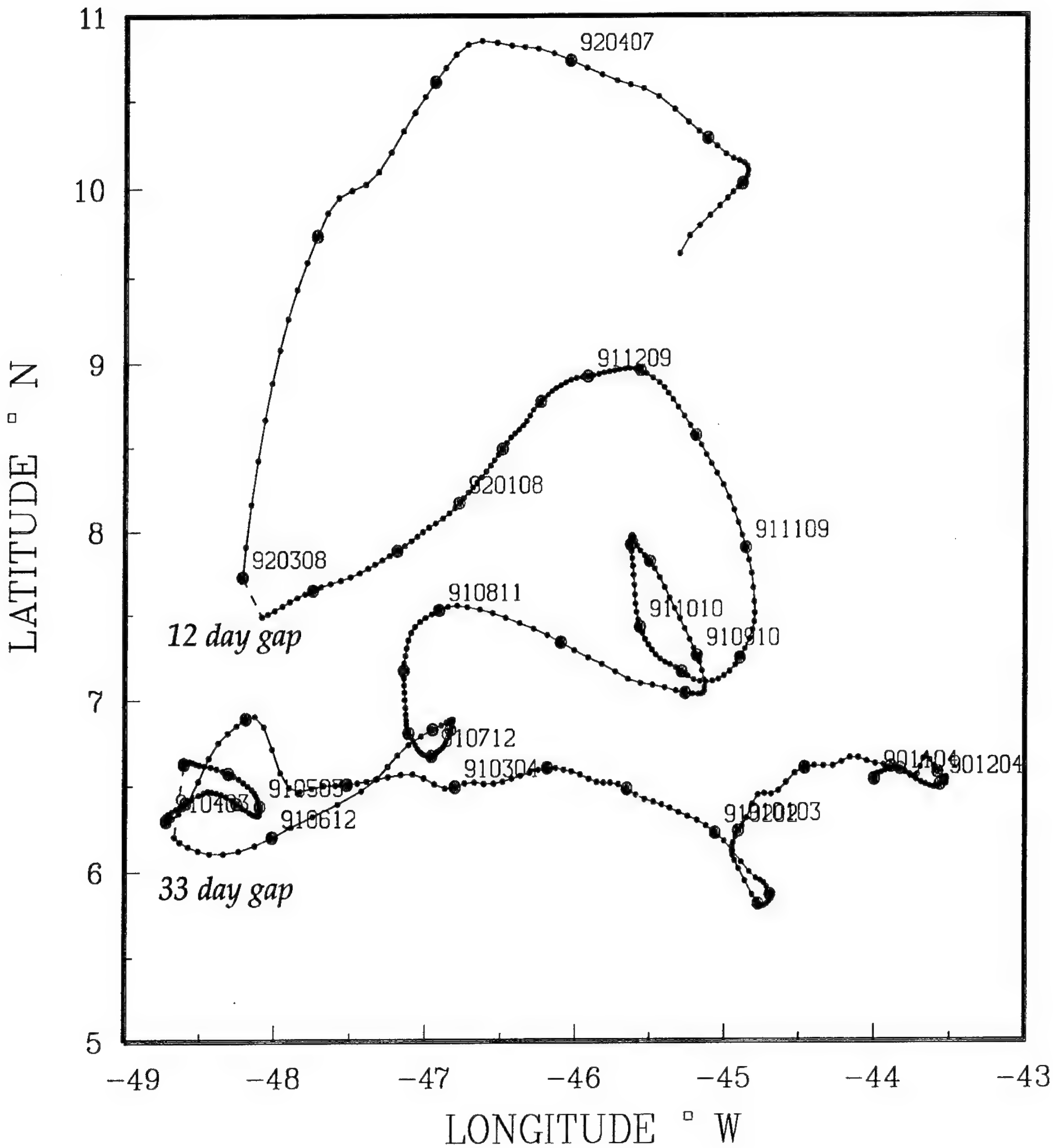


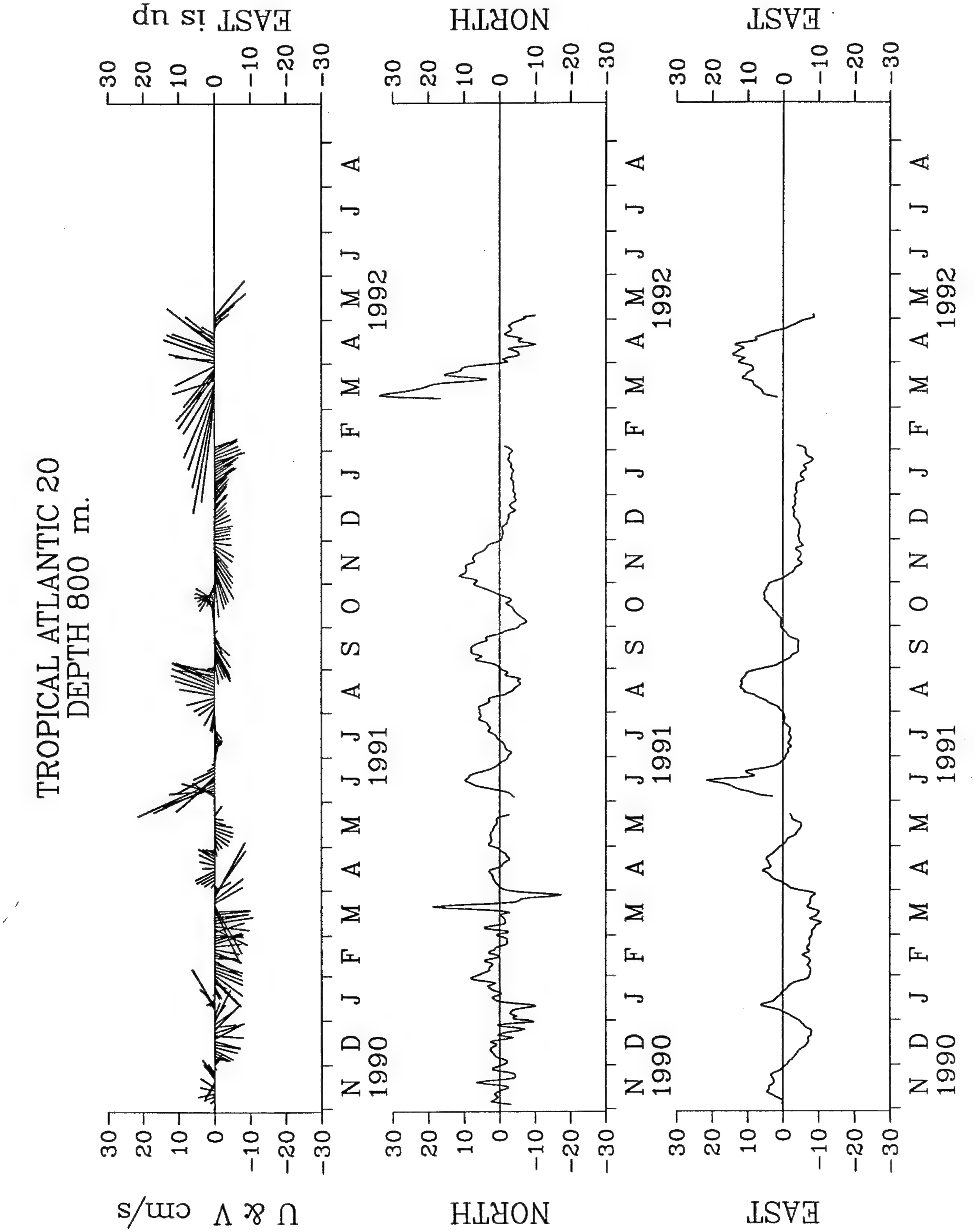


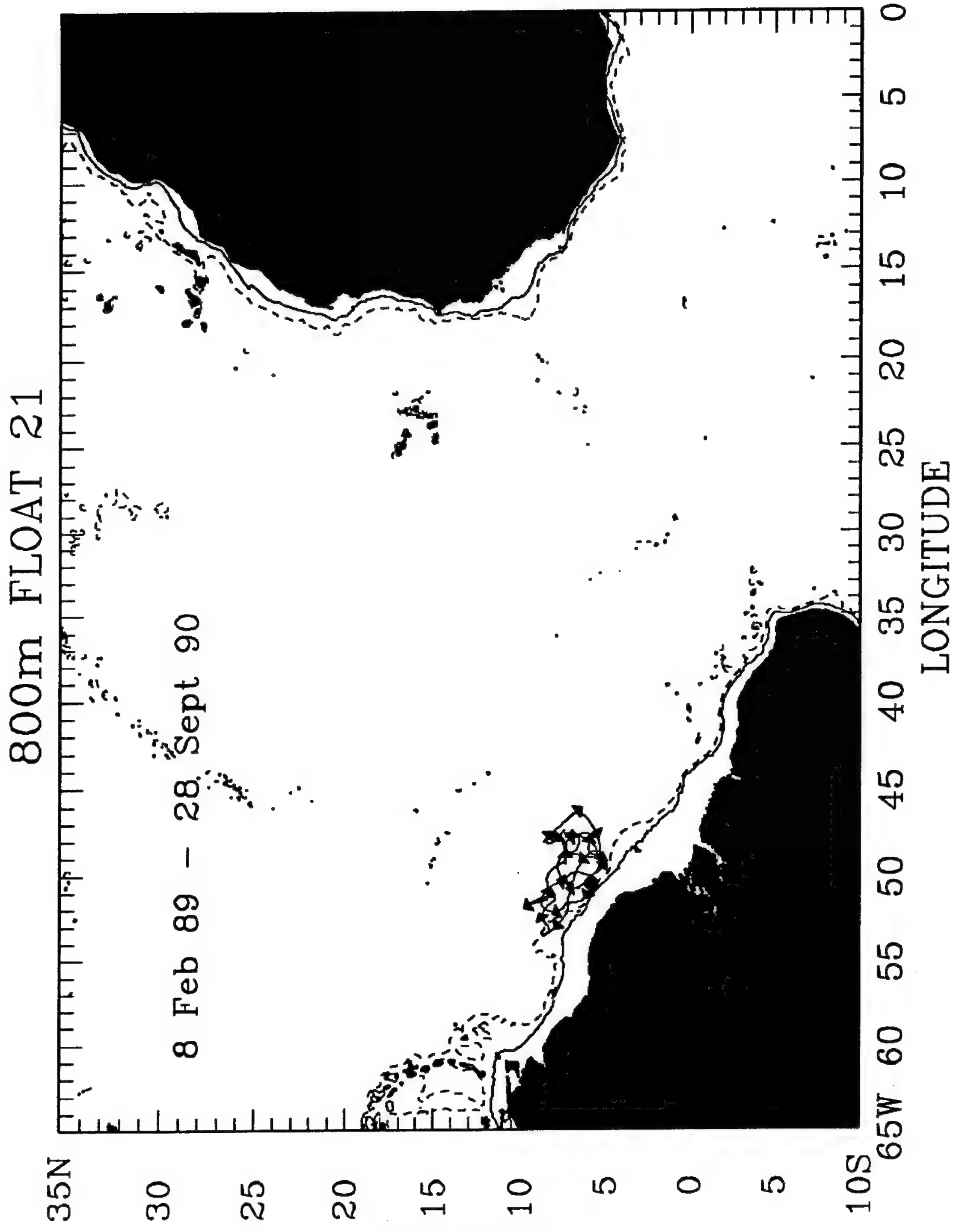
TROPICAL ATLANTIC 19
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30 20 10 0 −10 −20 −30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992


800m FLOAT 20
8 Feb 89 – 5 May 92
LONGITUDE
LATITUDE
65W 60 55 50 45 40 35 30 25 20 15 10 5 0
35N 30 25 20 15 10 5 0 5 10S

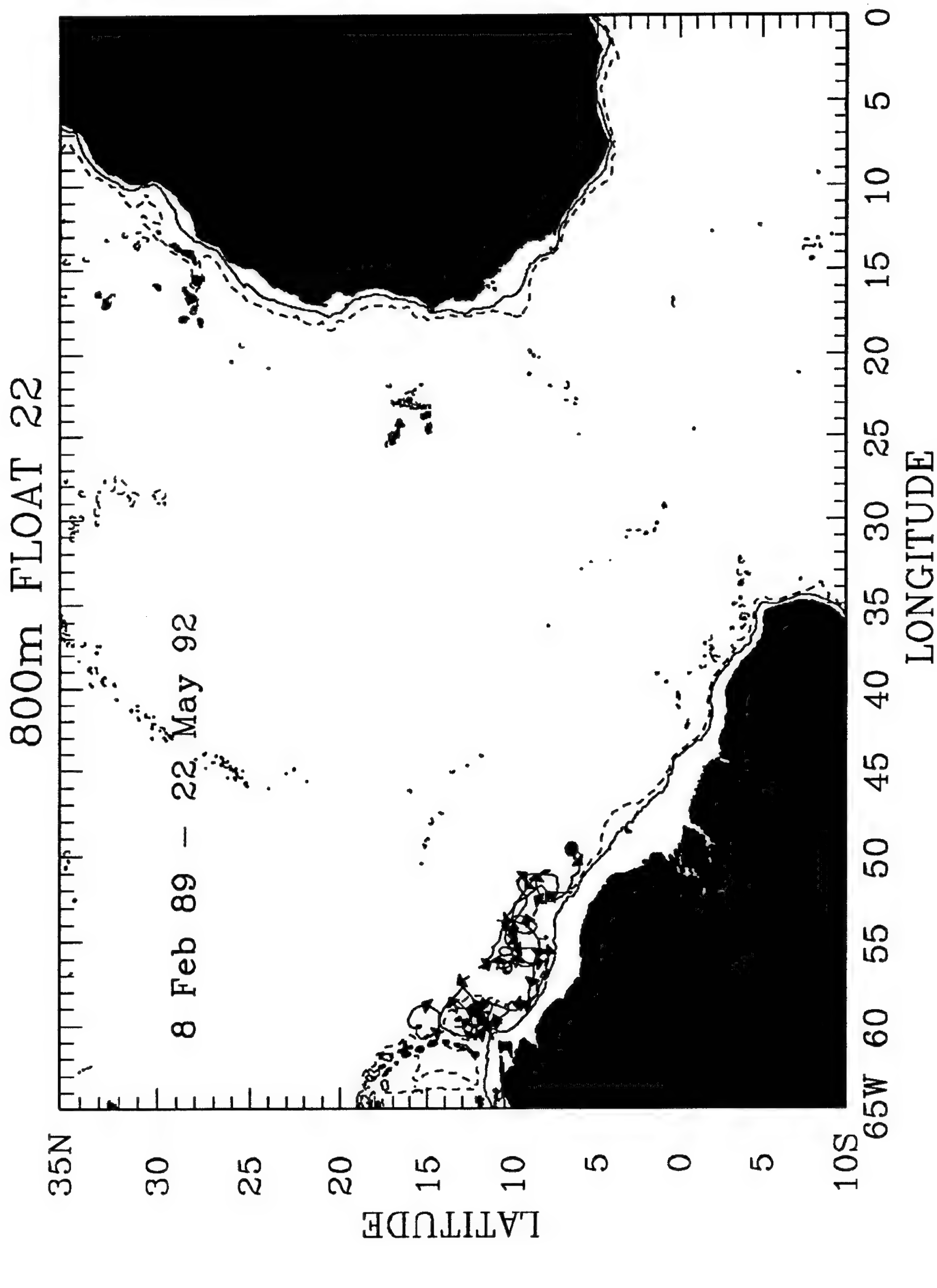
TROPICAL ATLANTIC 20




TROPICAL ATLANTIC 20
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992
30 20 10 0 -10 -20 -30

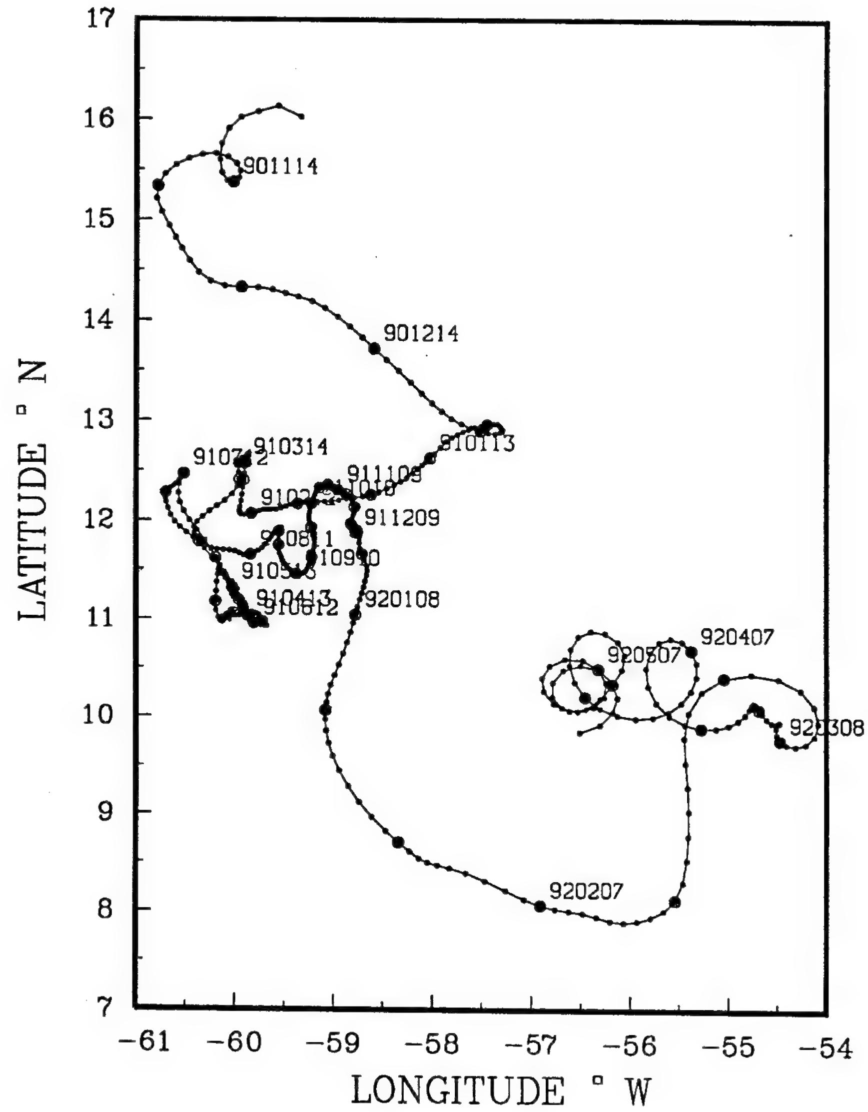


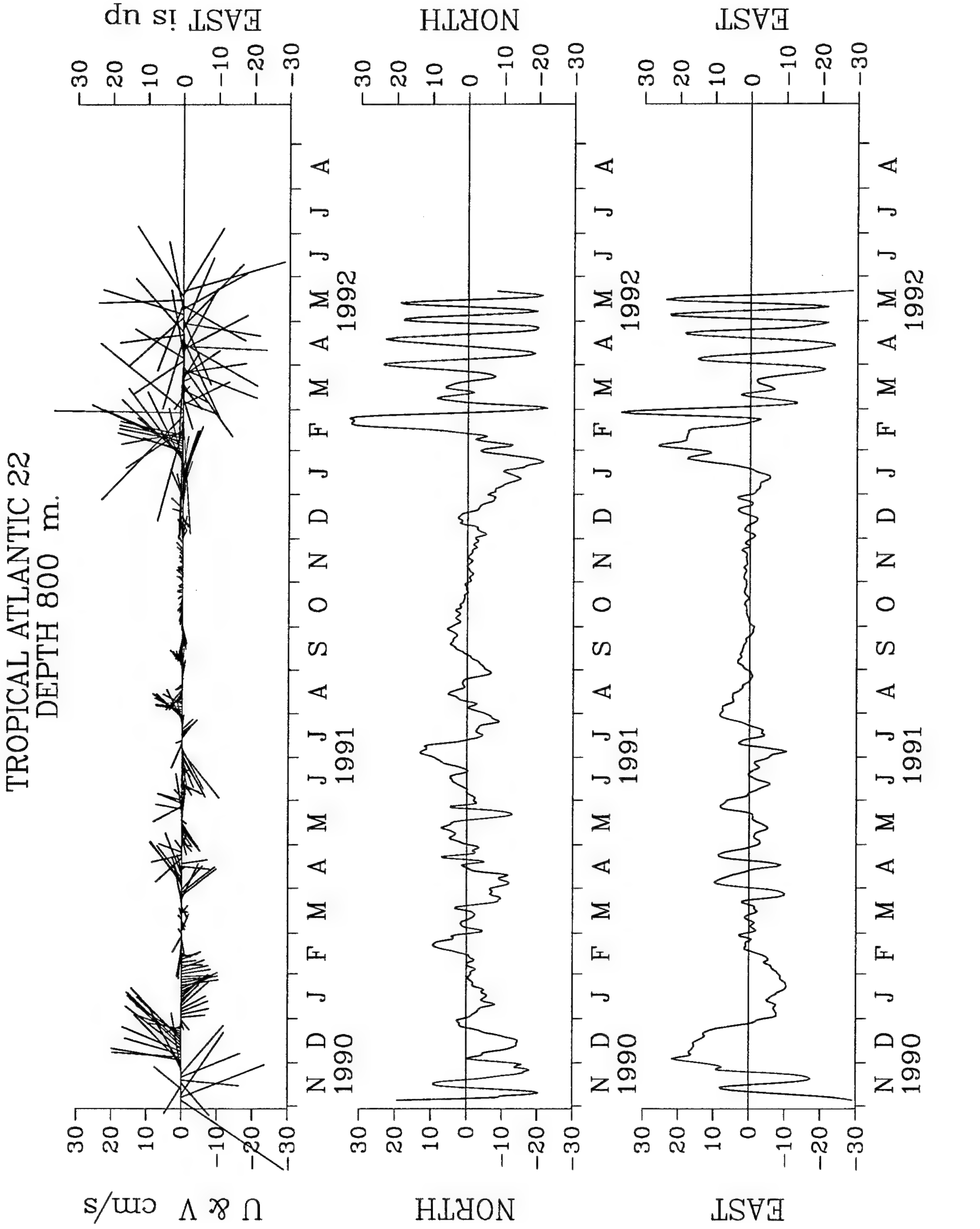
800m FLOAT 21
8 Feb 89 – 28 Sept 90
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

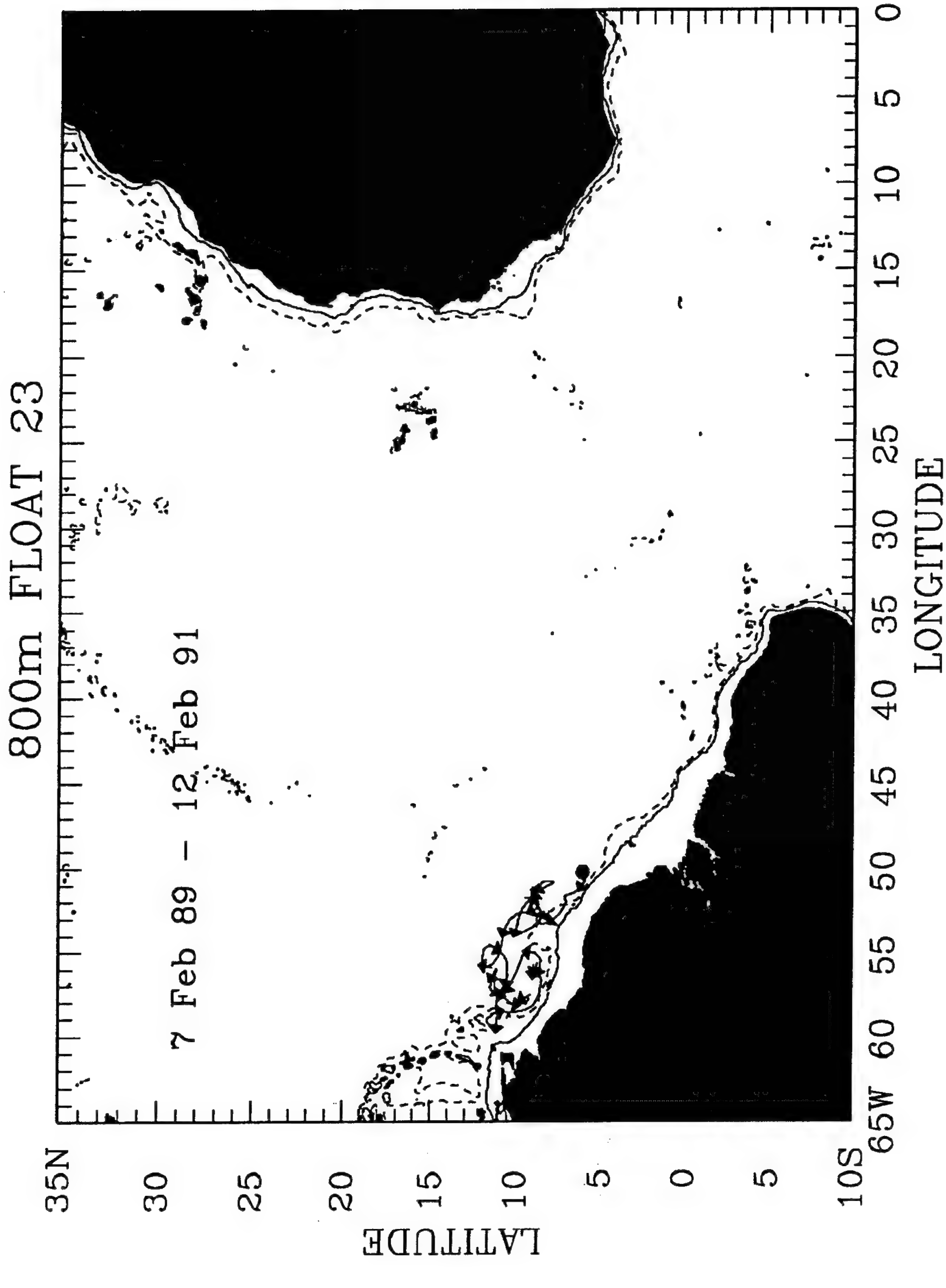


800m FLOAT 22
8 Feb 89 – 22 May 92
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0
LONGITUDE

TROPICAL ATLANTIC 22

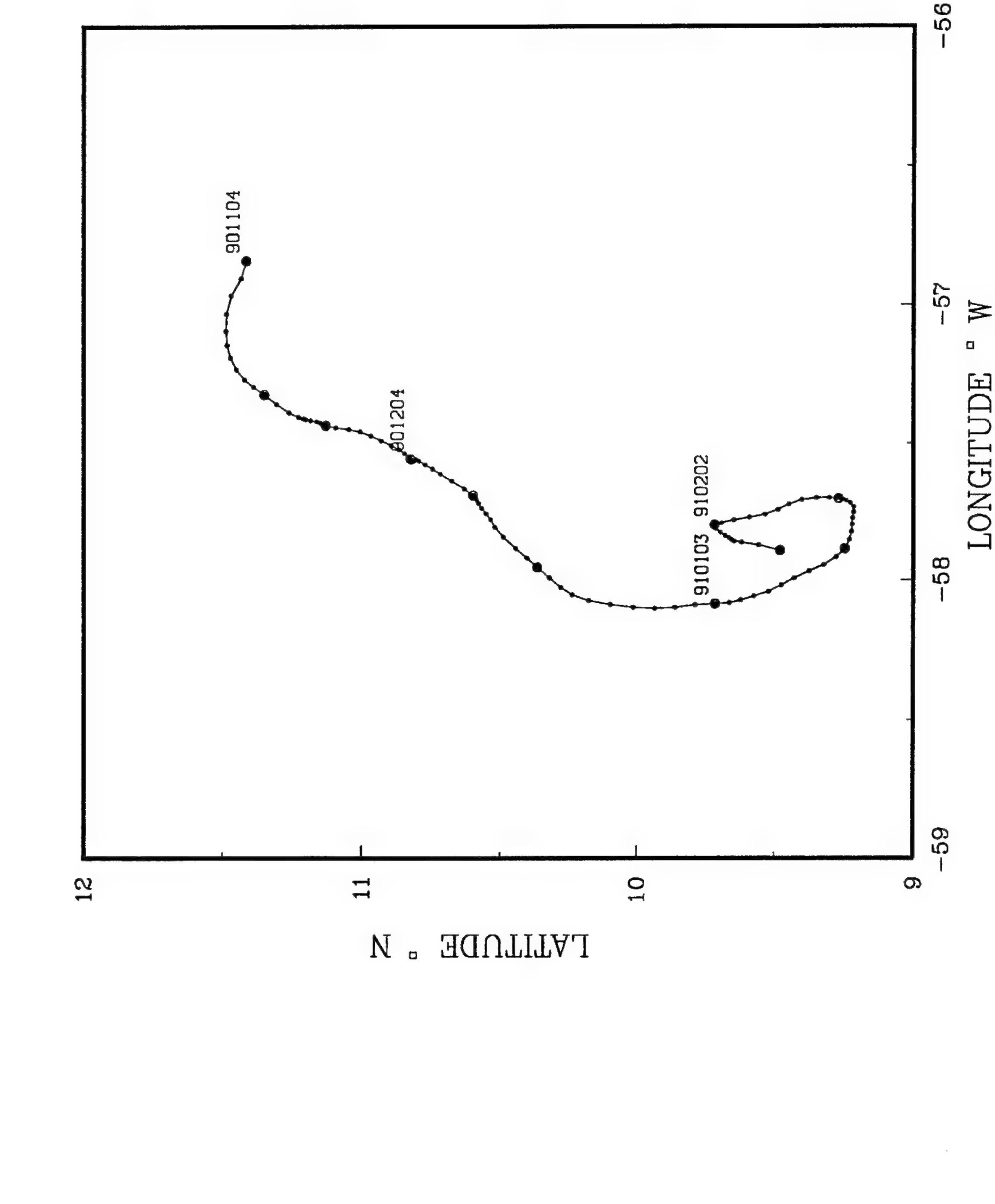



TROPICAL ATLANTIC 22
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30 20 10 0 −10 −20 −30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

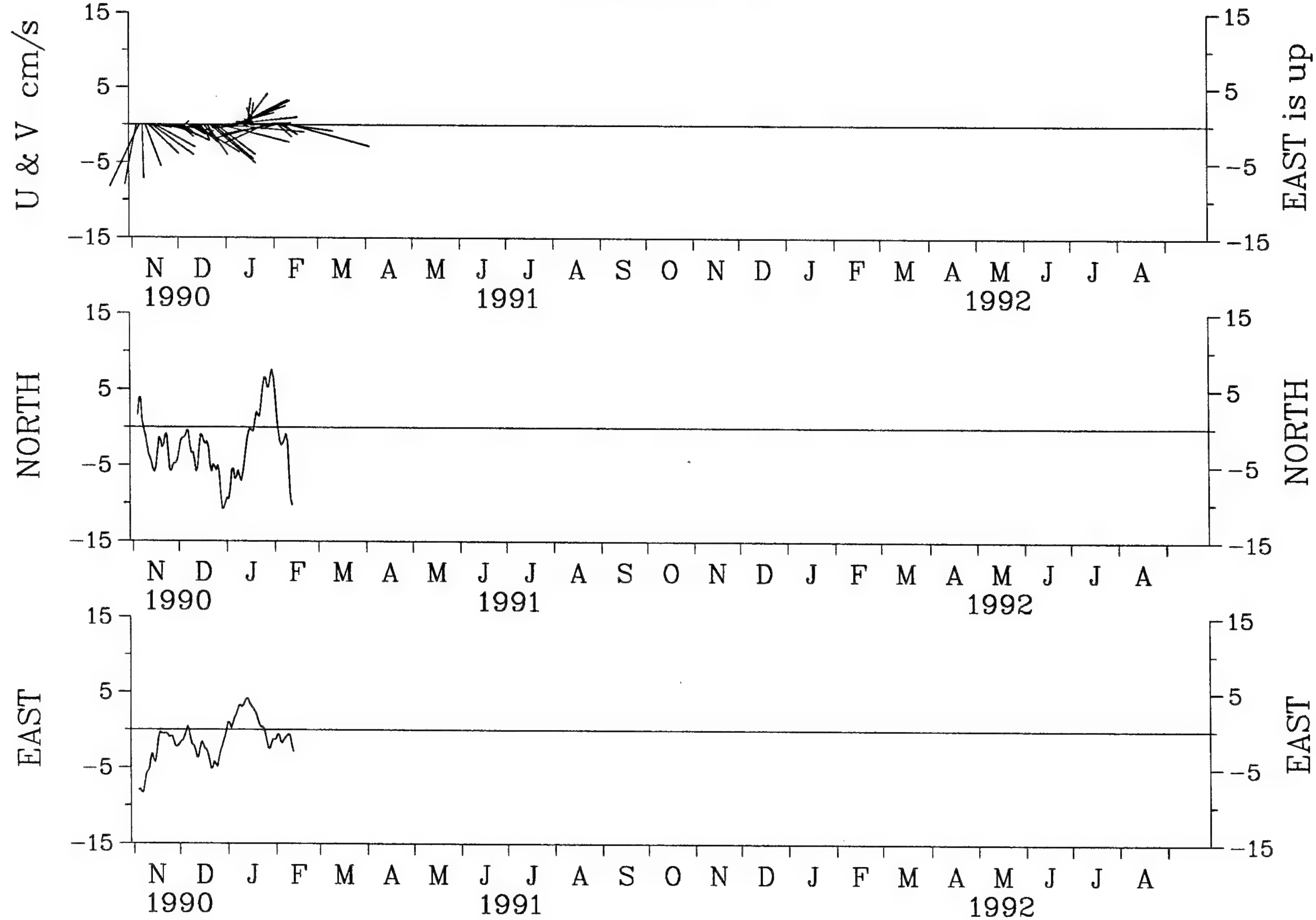


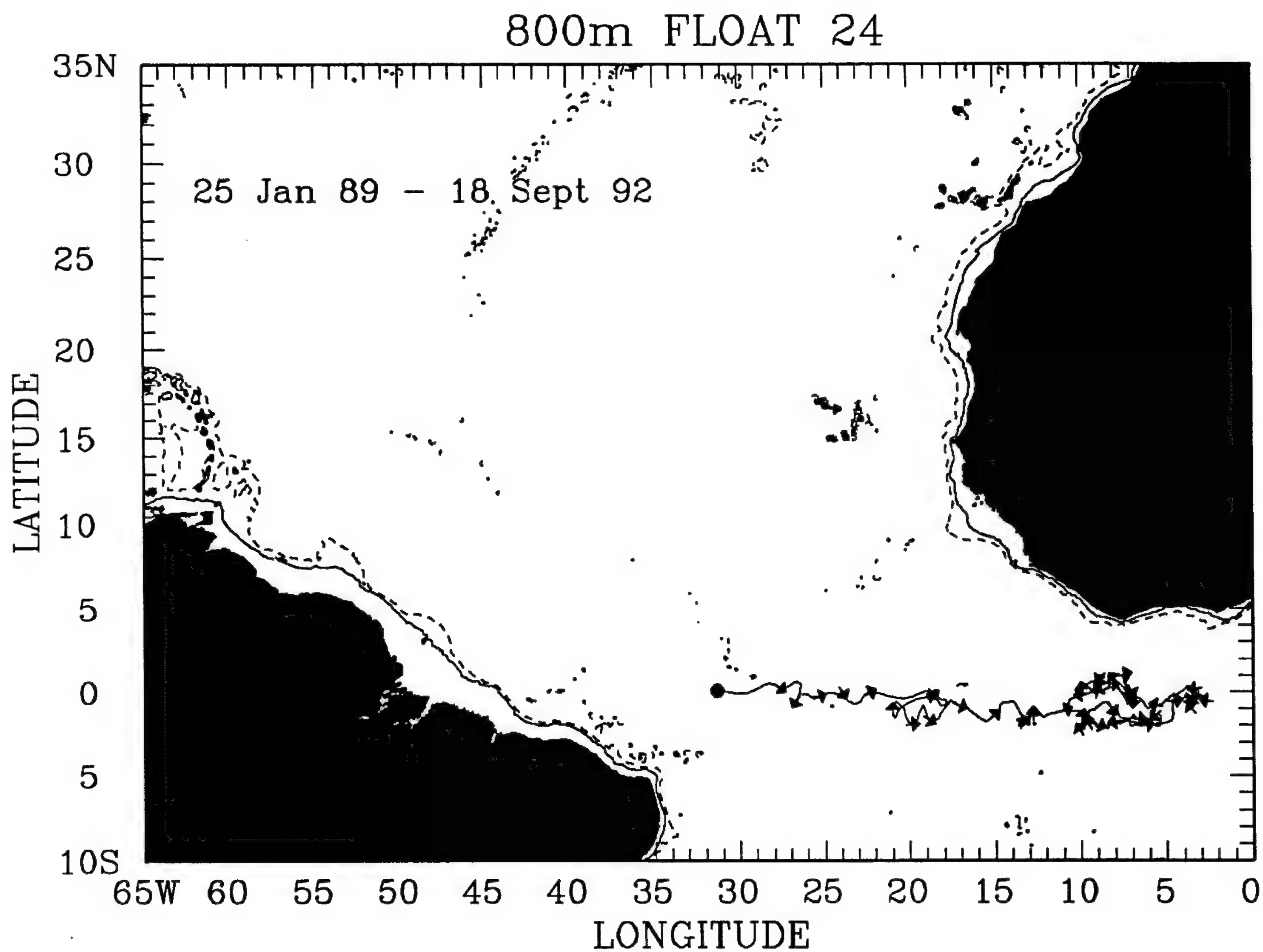
800m FLOAT 23
7 Feb 89 - 12 Feb 91
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

TROPICAL ATLANTIC 23

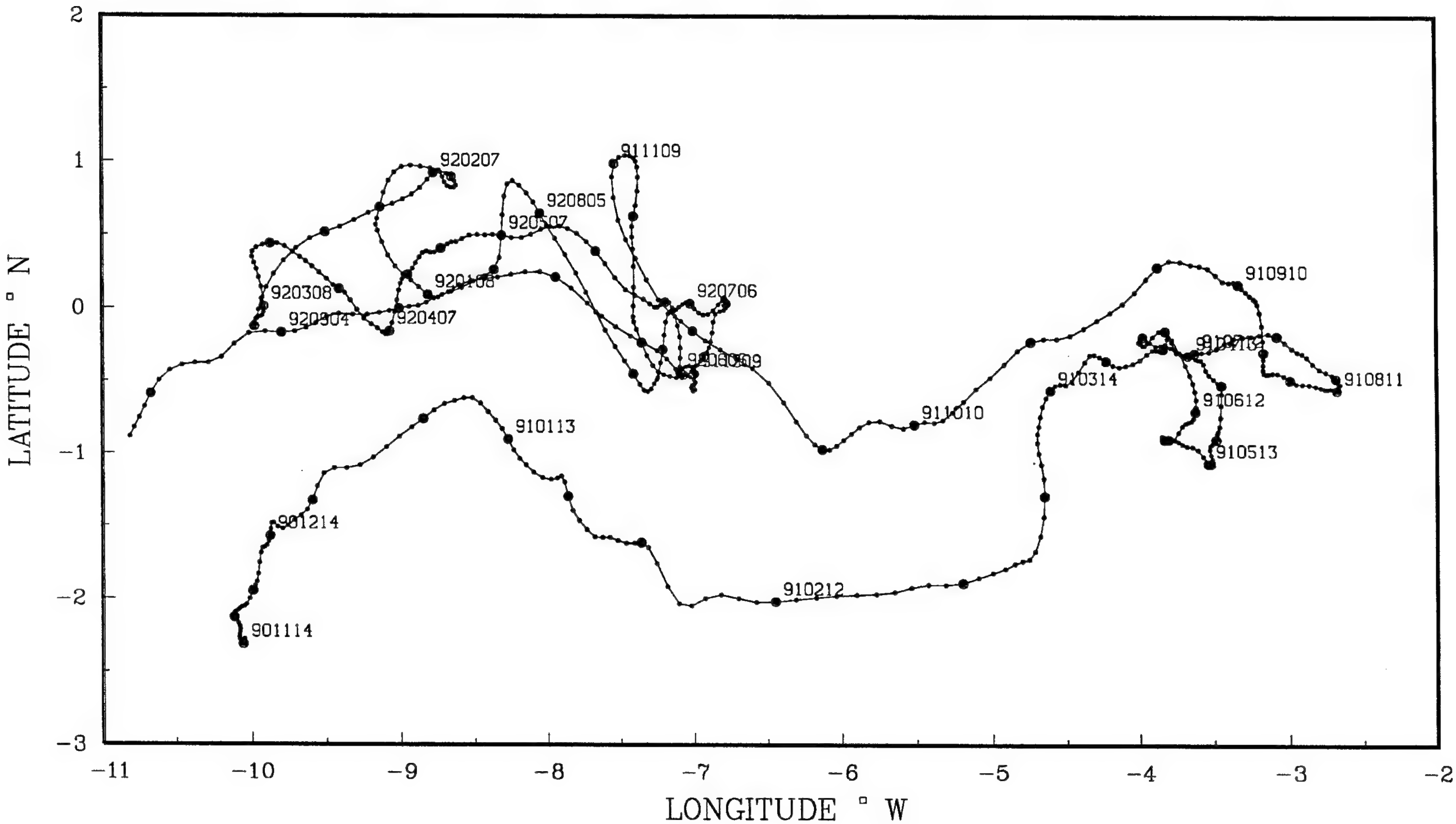


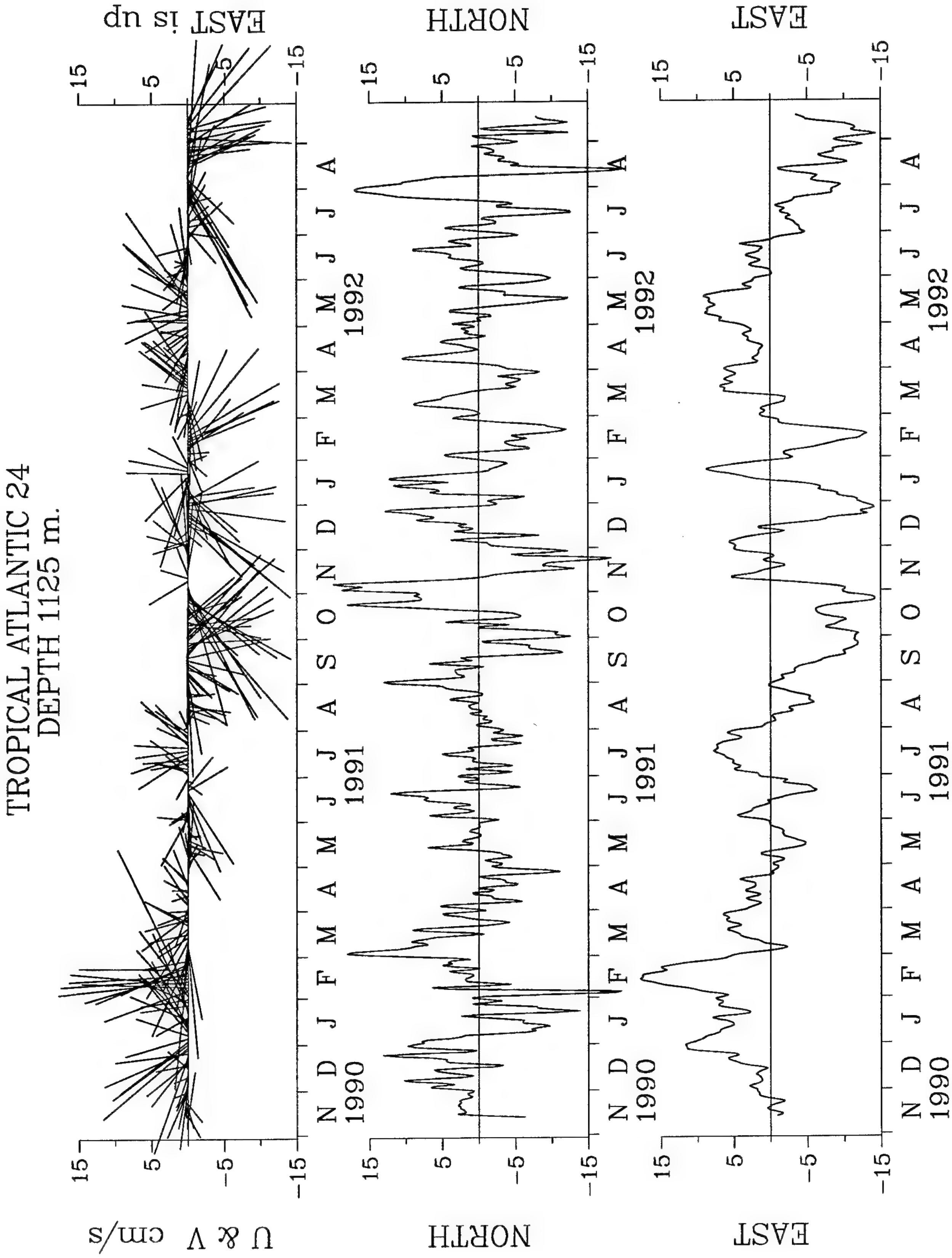
TROPICAL ATLANTIC 23
DEPTH 800 m.

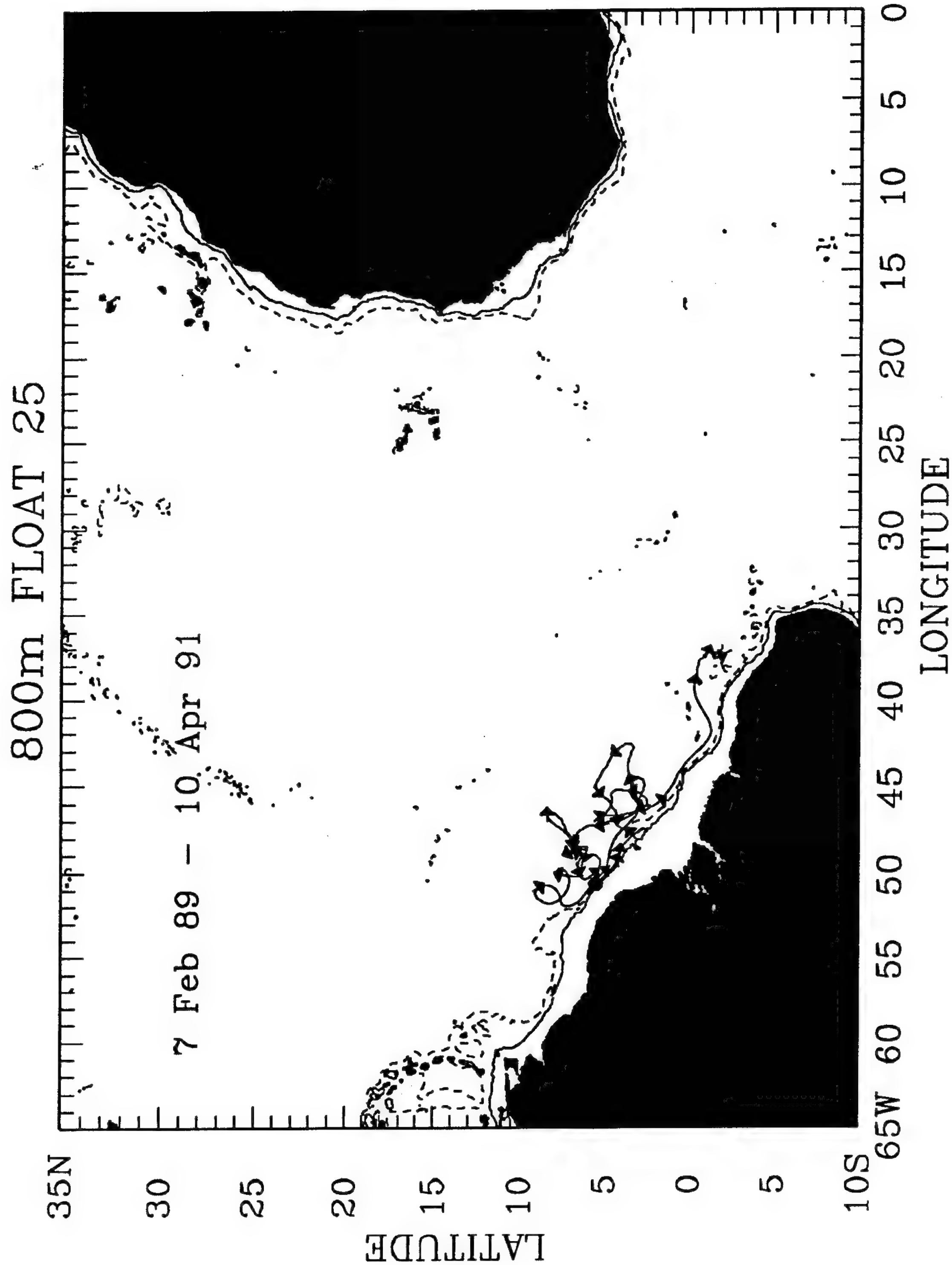



800m FLOAT 24
25 Jan 89 – 18 Sept 92
35N
30
25
20
15
10
5
0
5
10S
LATITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0
LONGITUDE

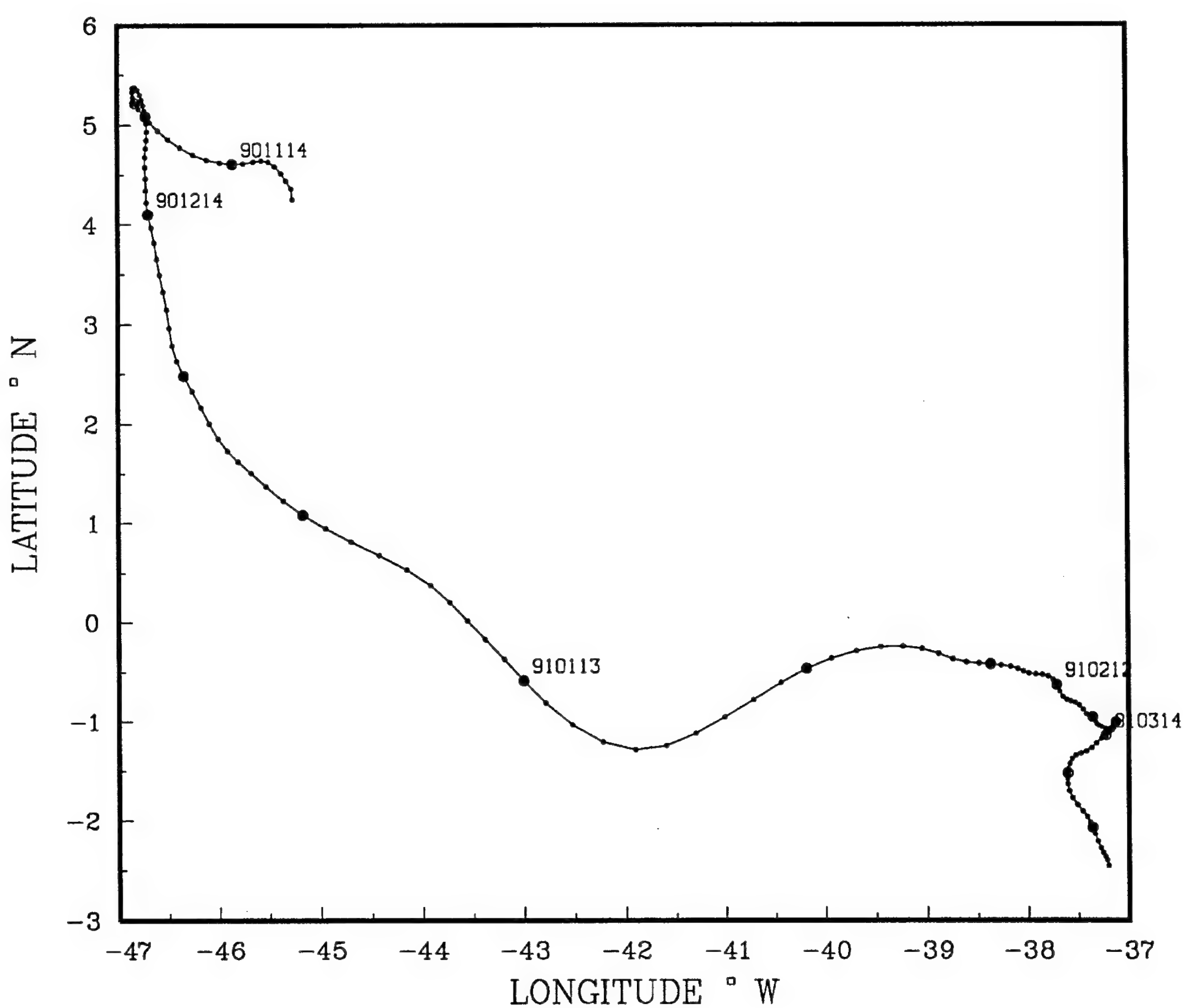
TROPICAL ATLANTIC 24

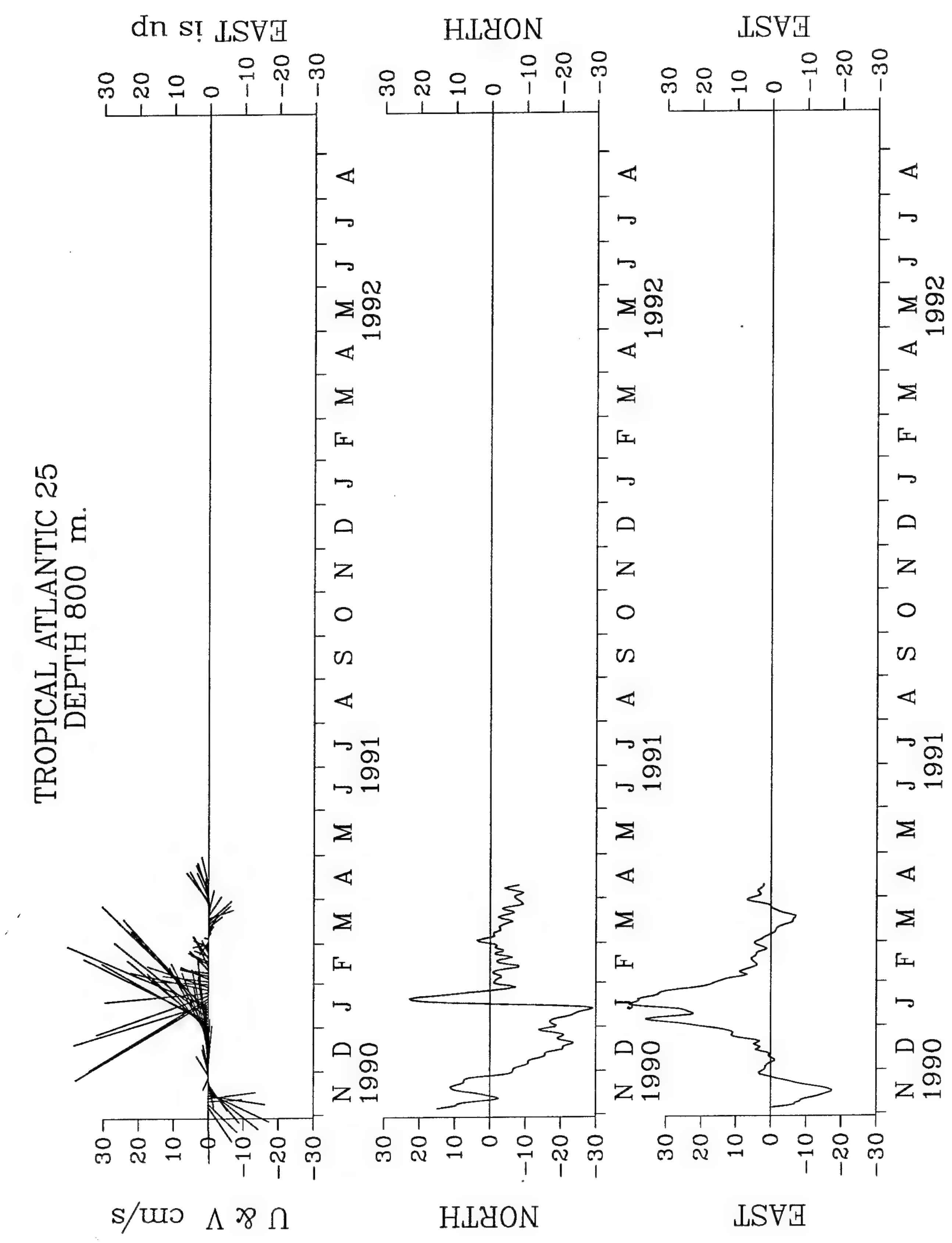


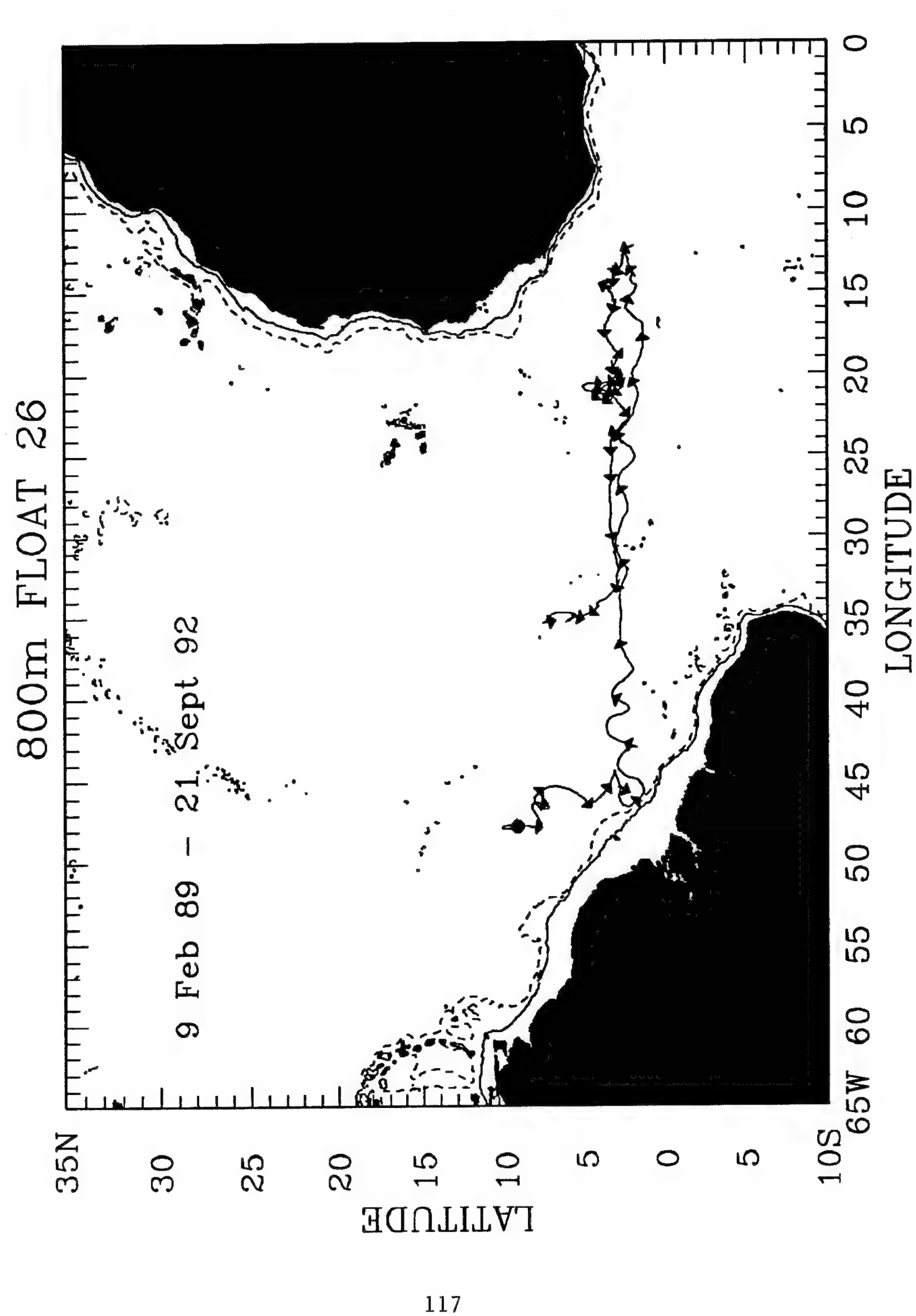

TROPICAL ATLANTIC 24
DEPTH 1125 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992


800m FLOAT 25
7 Feb 89 – 10 Apr 91
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

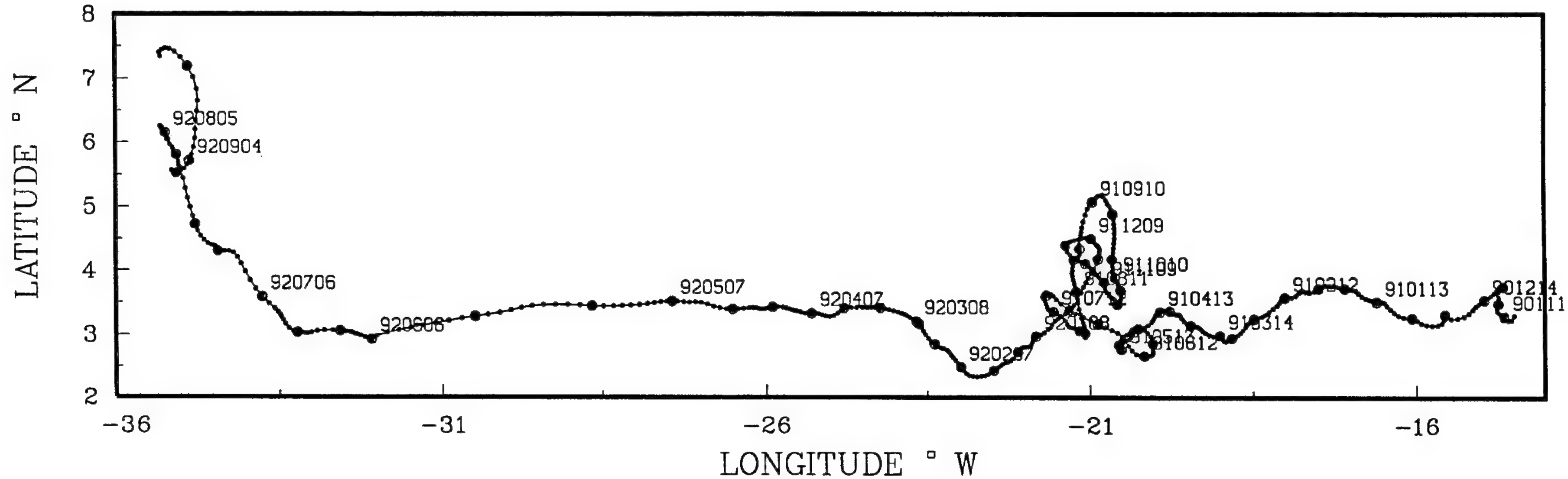
TROPICAL ATLANTIC 25

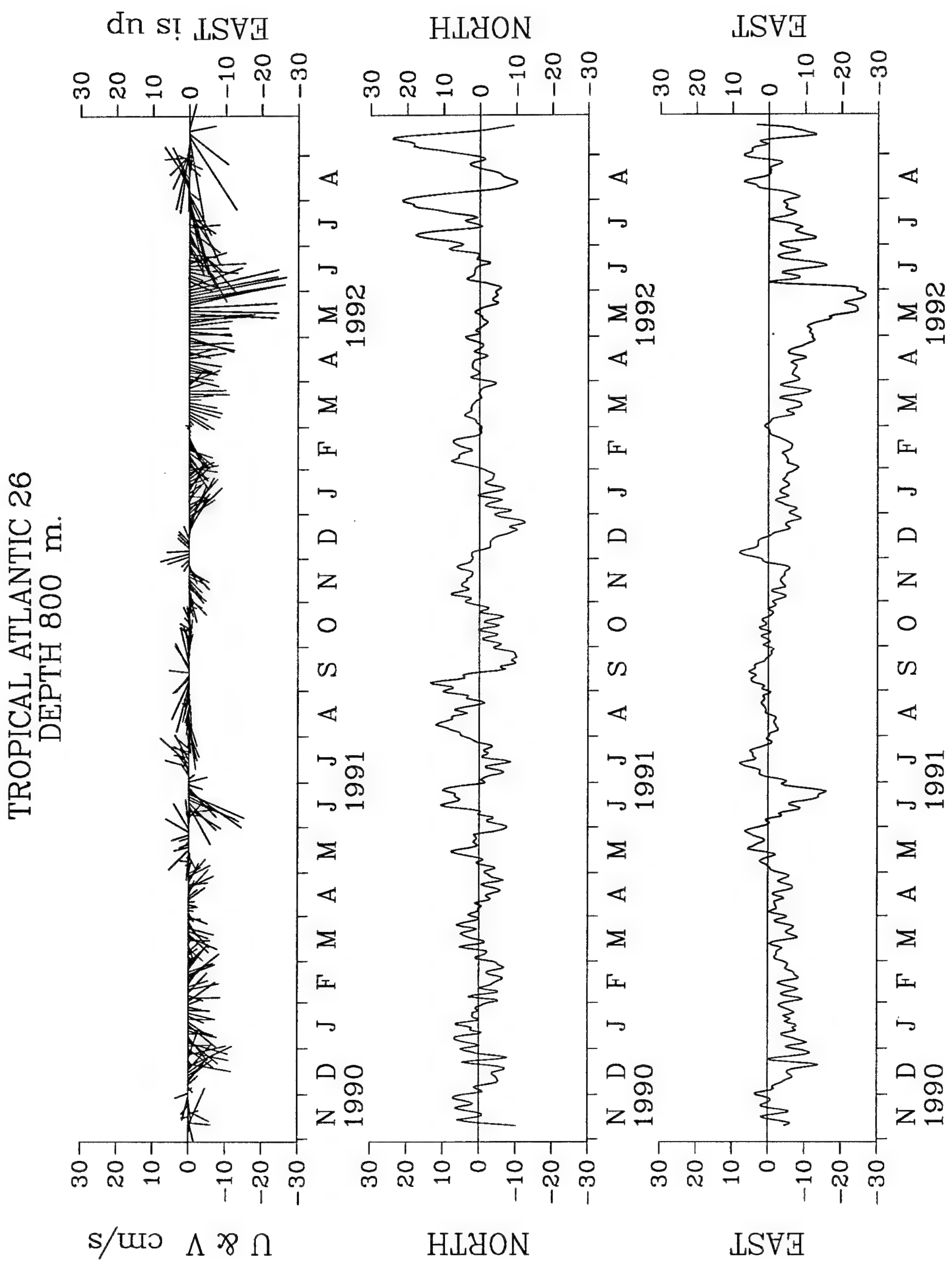



TROPICAL ATLANTIC 25
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

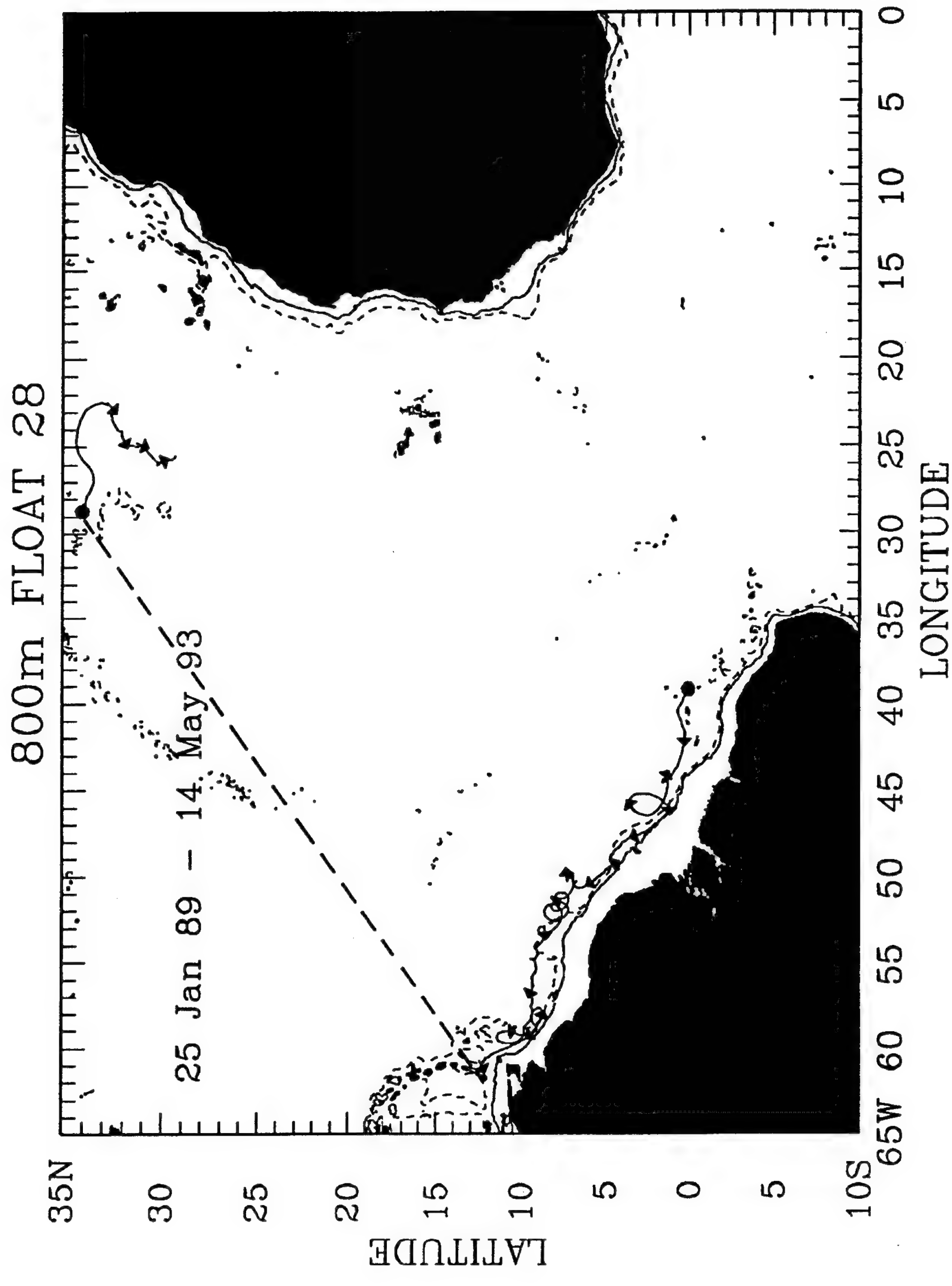

800m FLOAT 26
9 Feb 89 - 21 Sept 92
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

TROPICAL ATLANTIC 26

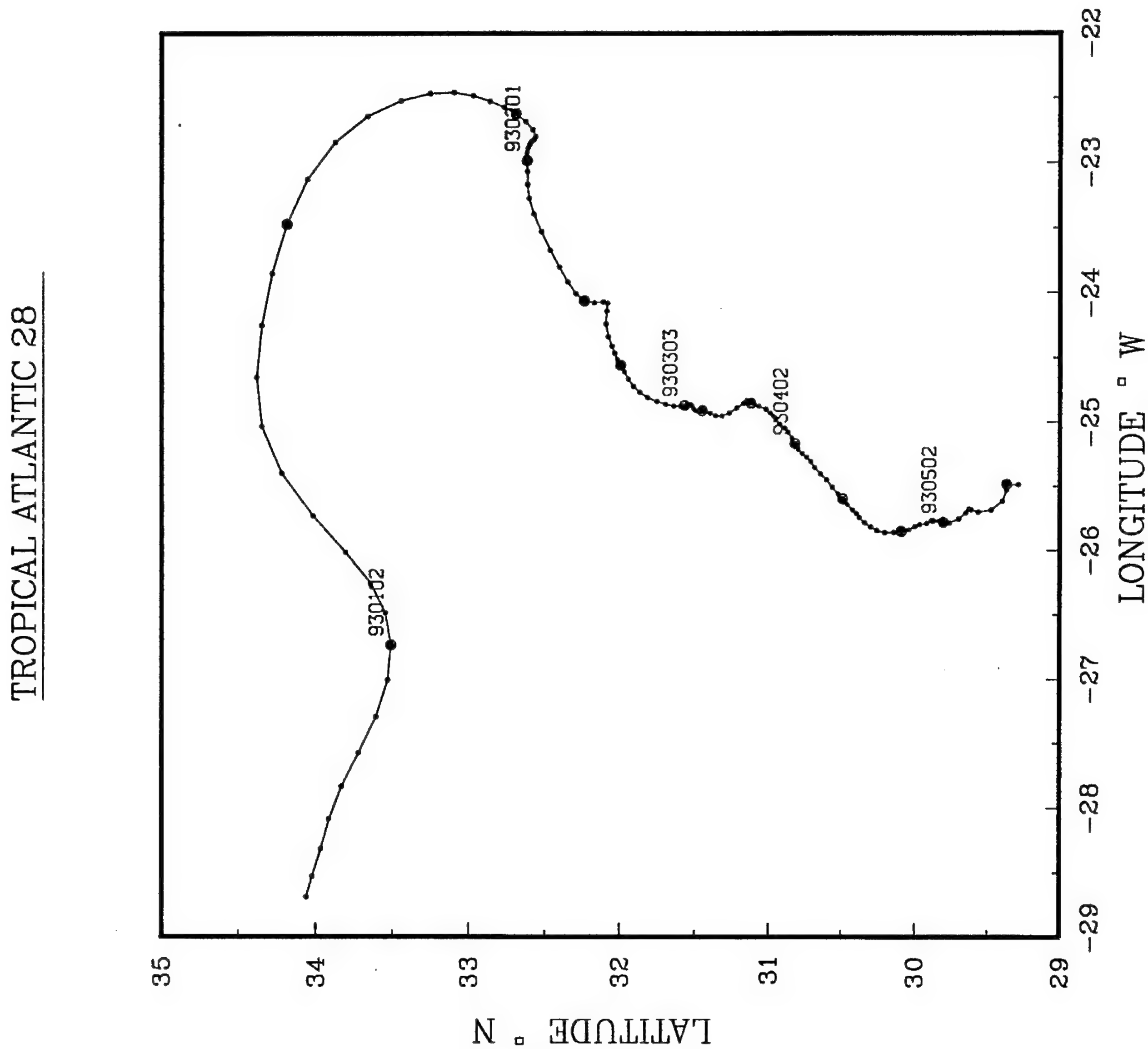


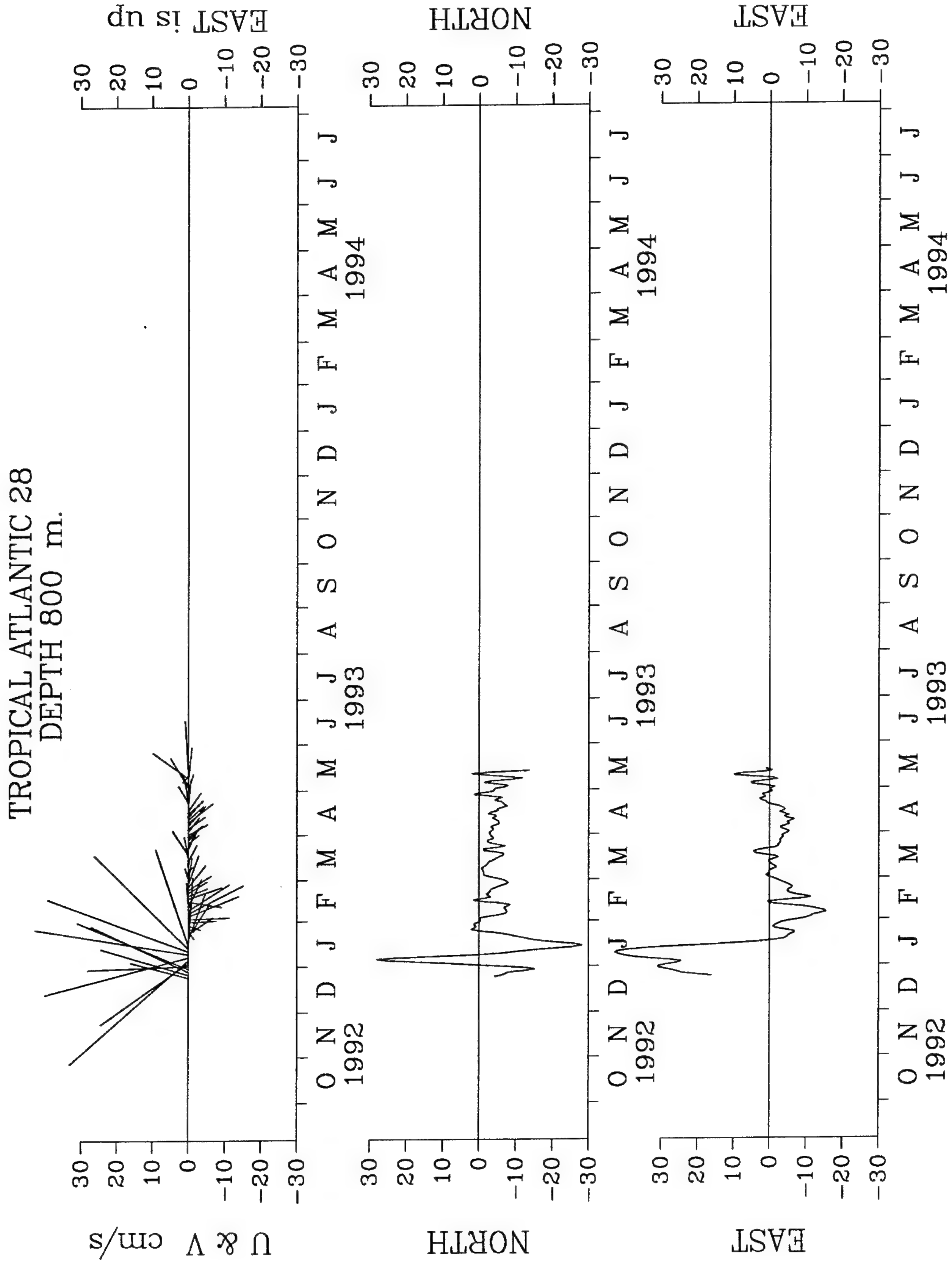


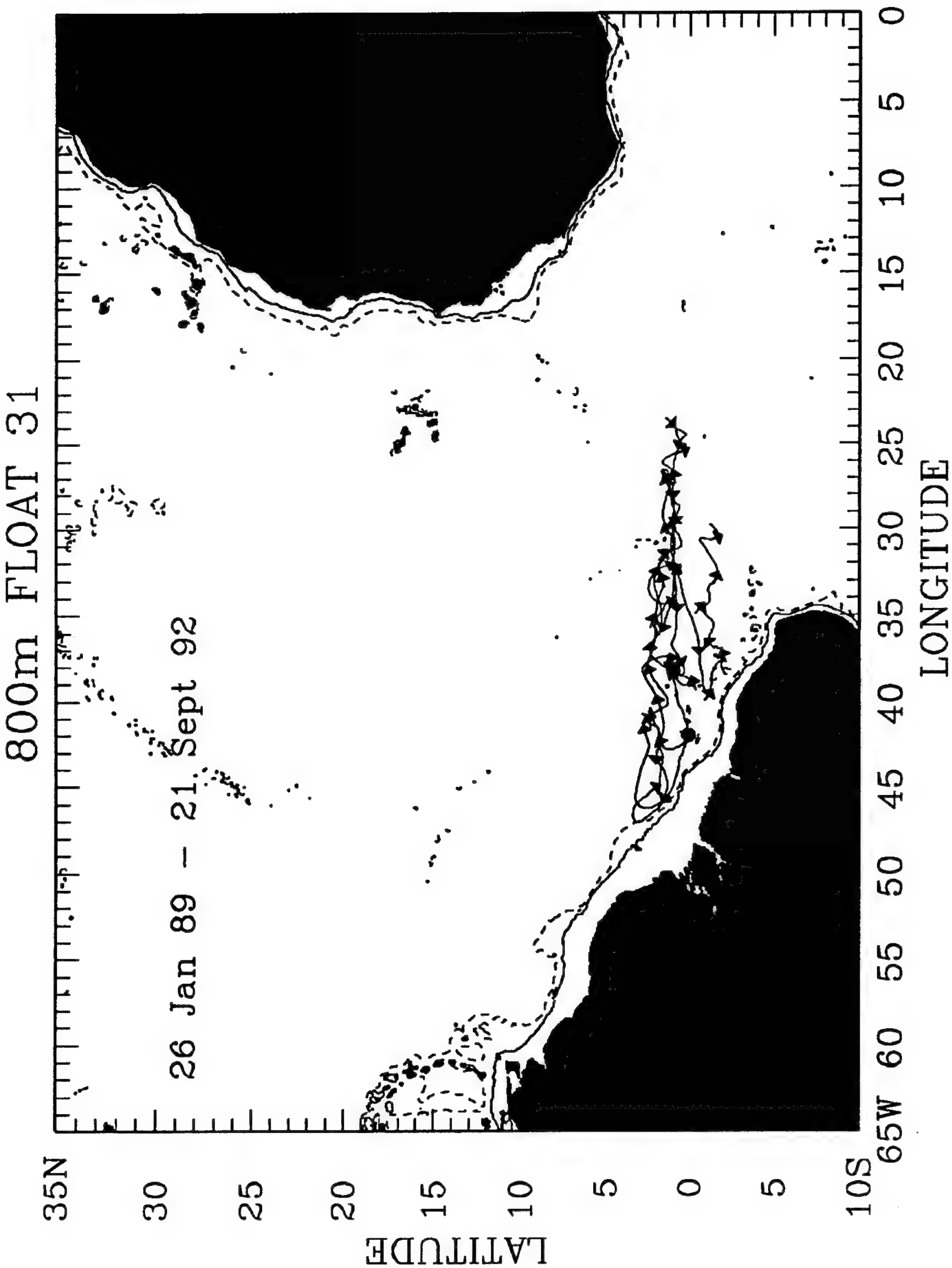
TROPICAL ATLANTIC 26
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30
20
10
0
−10
−20
−30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992



800m FLOAT 28
25 Jan 89 – 14 May 93
LATITUDE
35N
30
25
20
15
10
5
0
5
10S
LONGITUDE
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

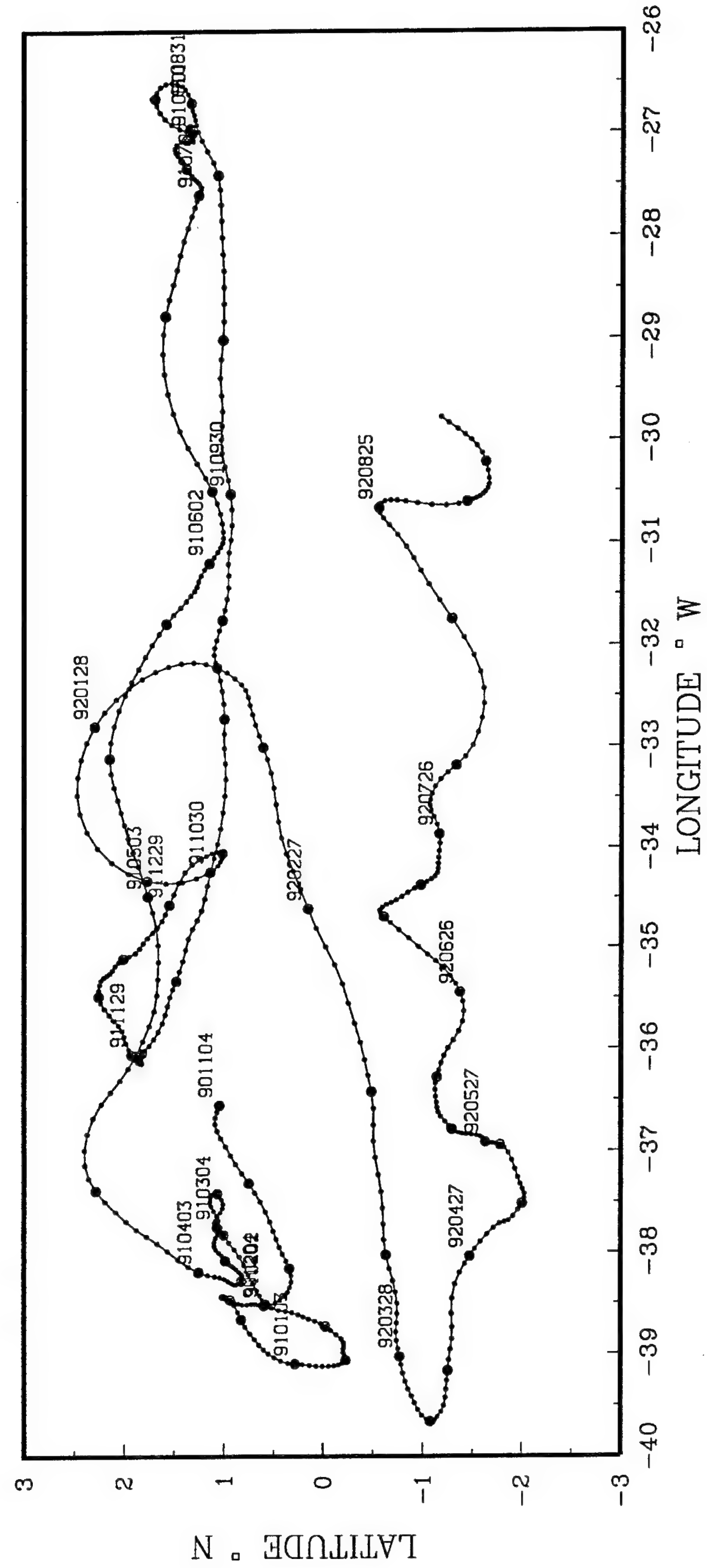

TROPICAL ATLANTIC 28
LATITUDE ° N
35
34
33
32
31
30
29
LONGITUDE ° W
−29
−28
−27
−26
−25
−24
−23
−22
930102
930303
930402
930502

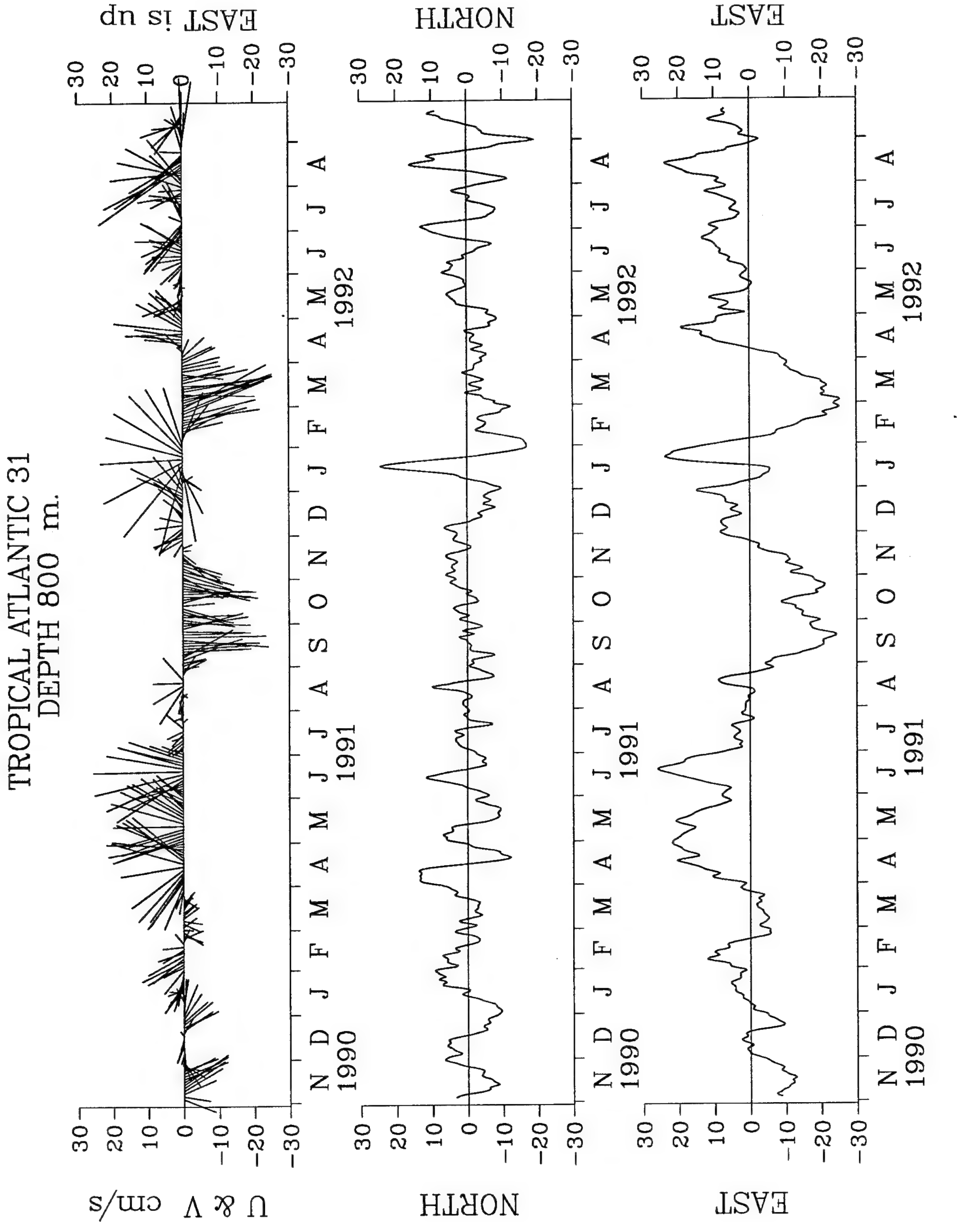

TROPICAL ATLANTIC 28
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30 20 10 0 −10 −20 −30
O N D J F M A M J J A S O N D J F M A M J J
1992
1993
1994

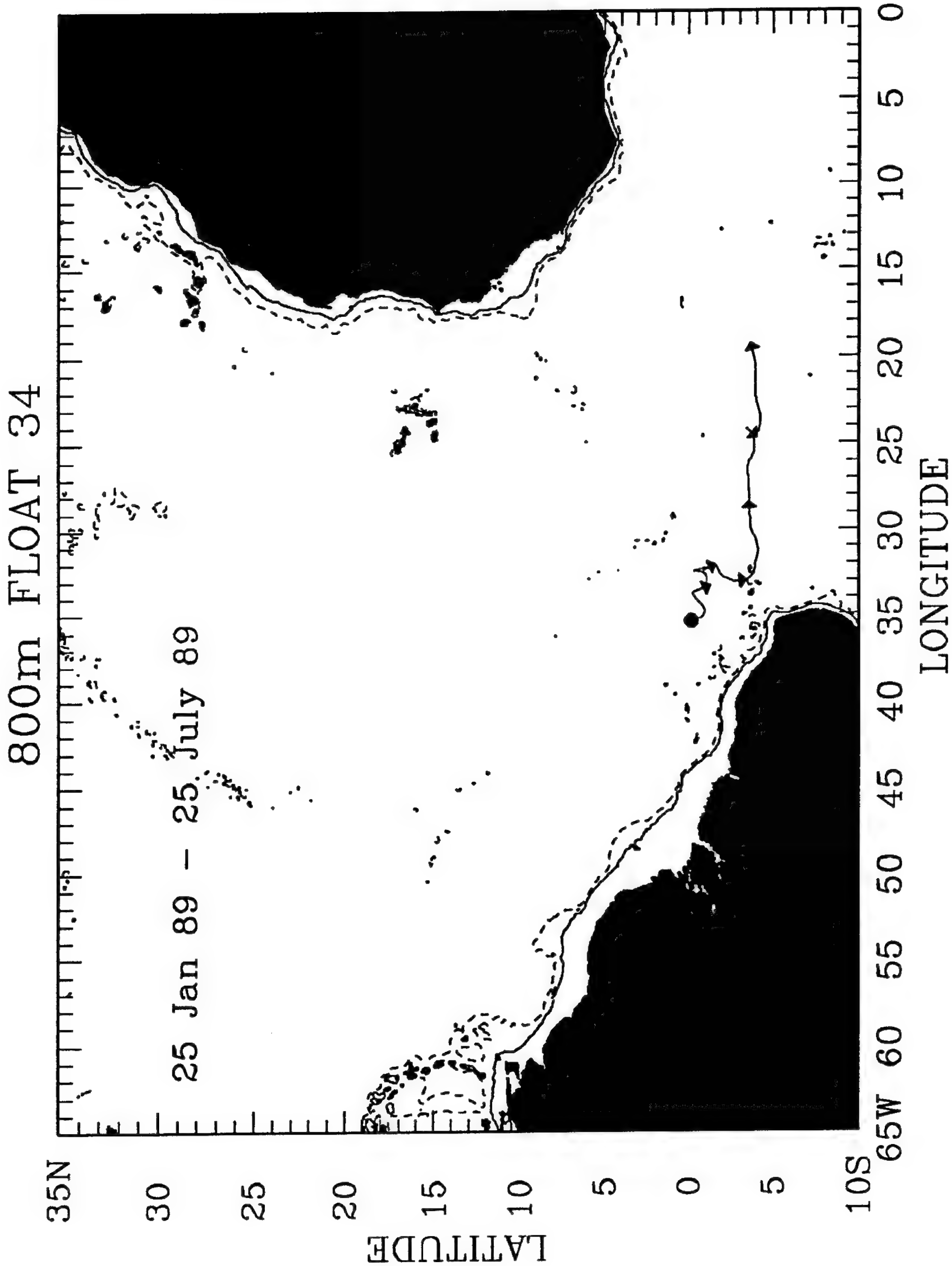


800m FLOAT 31
26 Jan 89 – 21 Sept 92
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

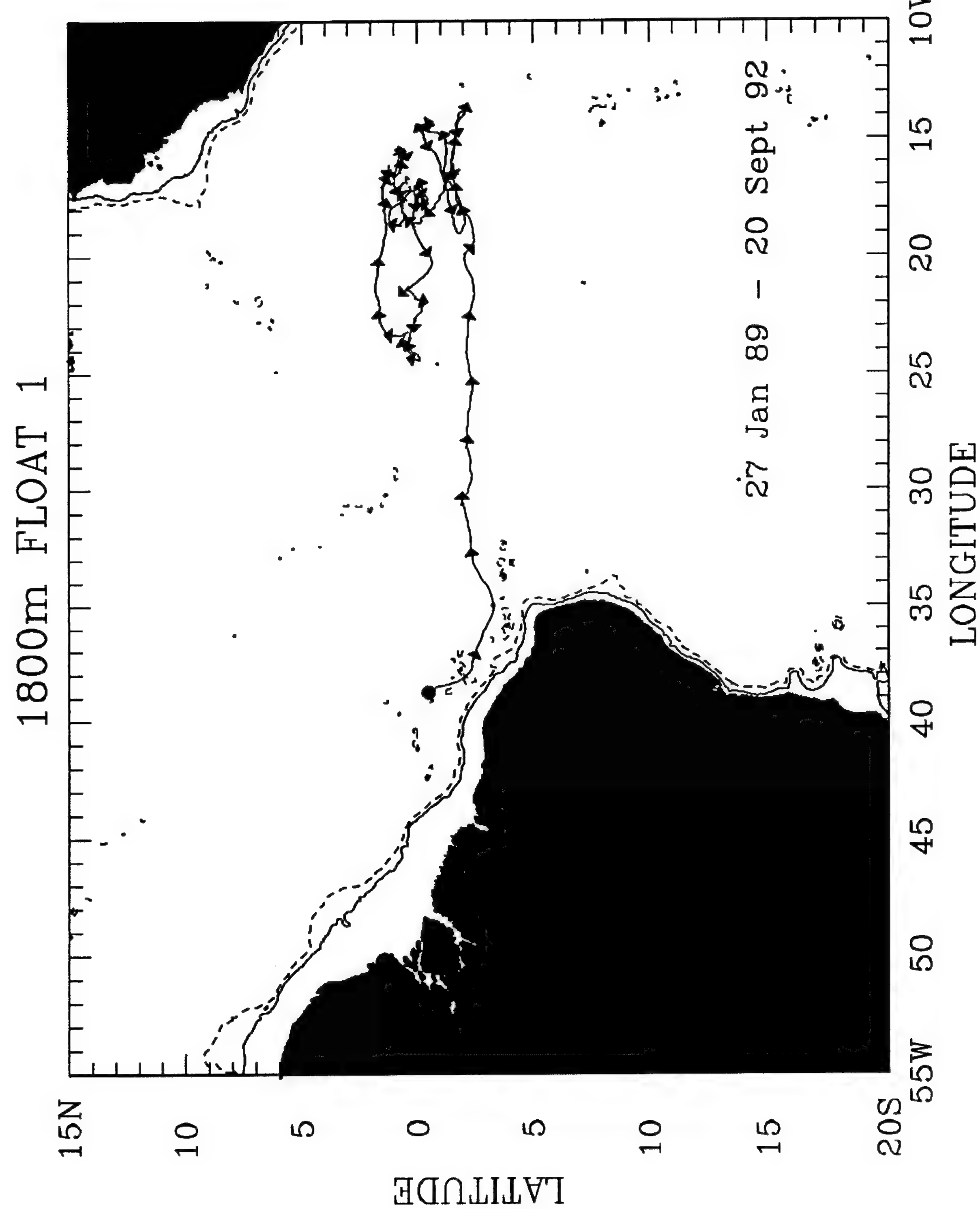
TROPICAL ATLANTIC 31



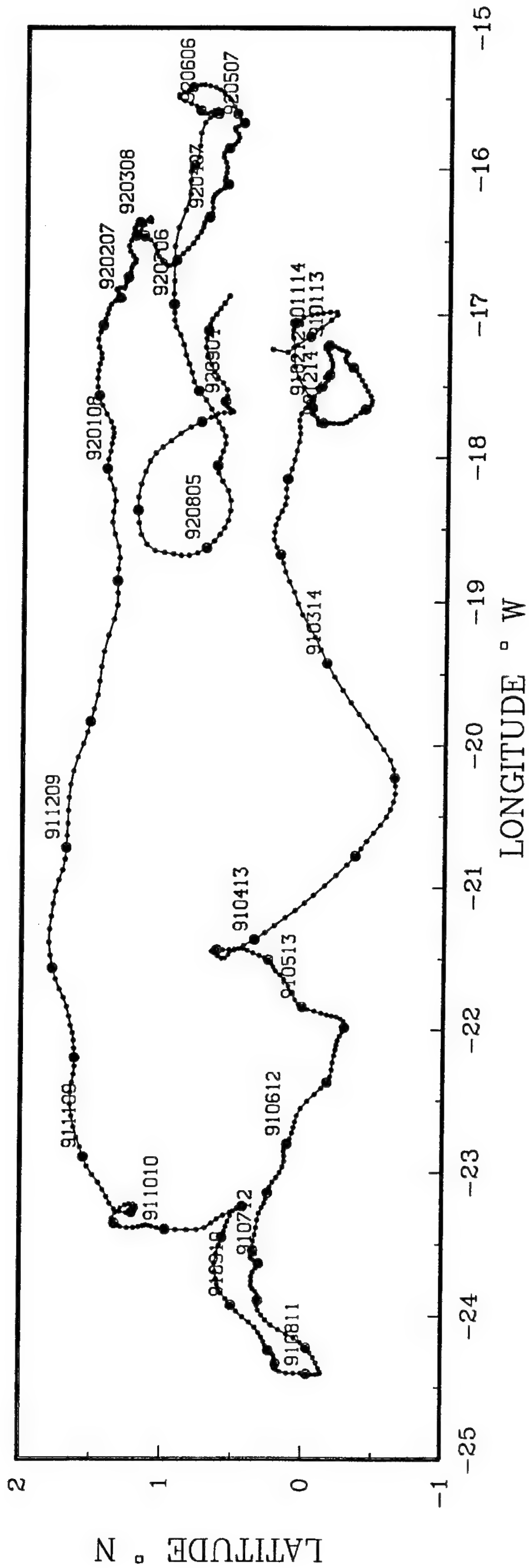

TROPICAL ATLANTIC 31
DEPTH 800 m.
U & V cm/s
EAST is up
NORTH
EAST
30 20 10 0 −10 −20 −30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992



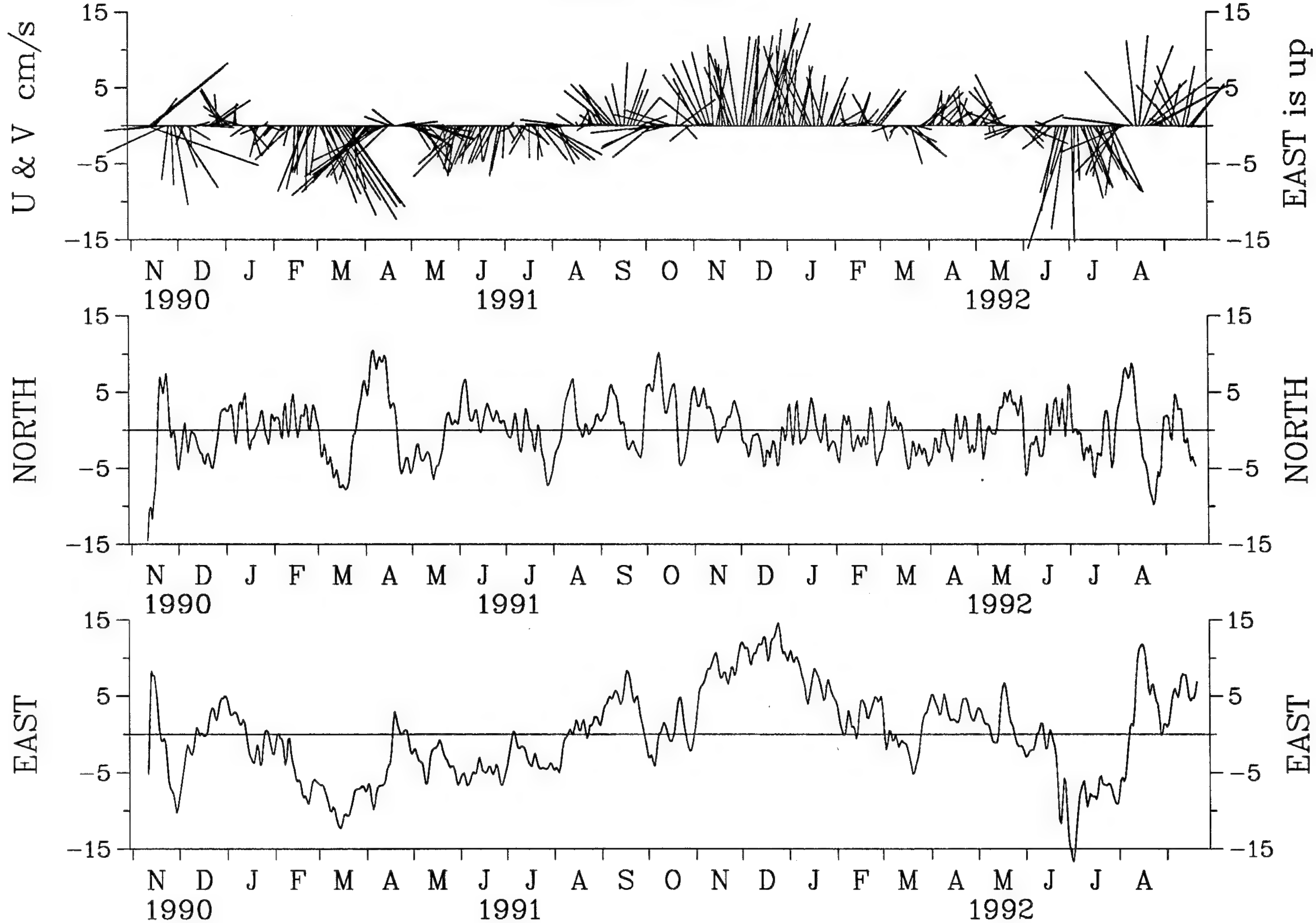
800m FLOAT 34
25 Jan 89 - 25 July 89
LATITUDE
LONGITUDE
35N
30
25
20
15
10
5
0
5
10S
65W
60
55
50
45
40
35
30
25
20
15
10
5
0

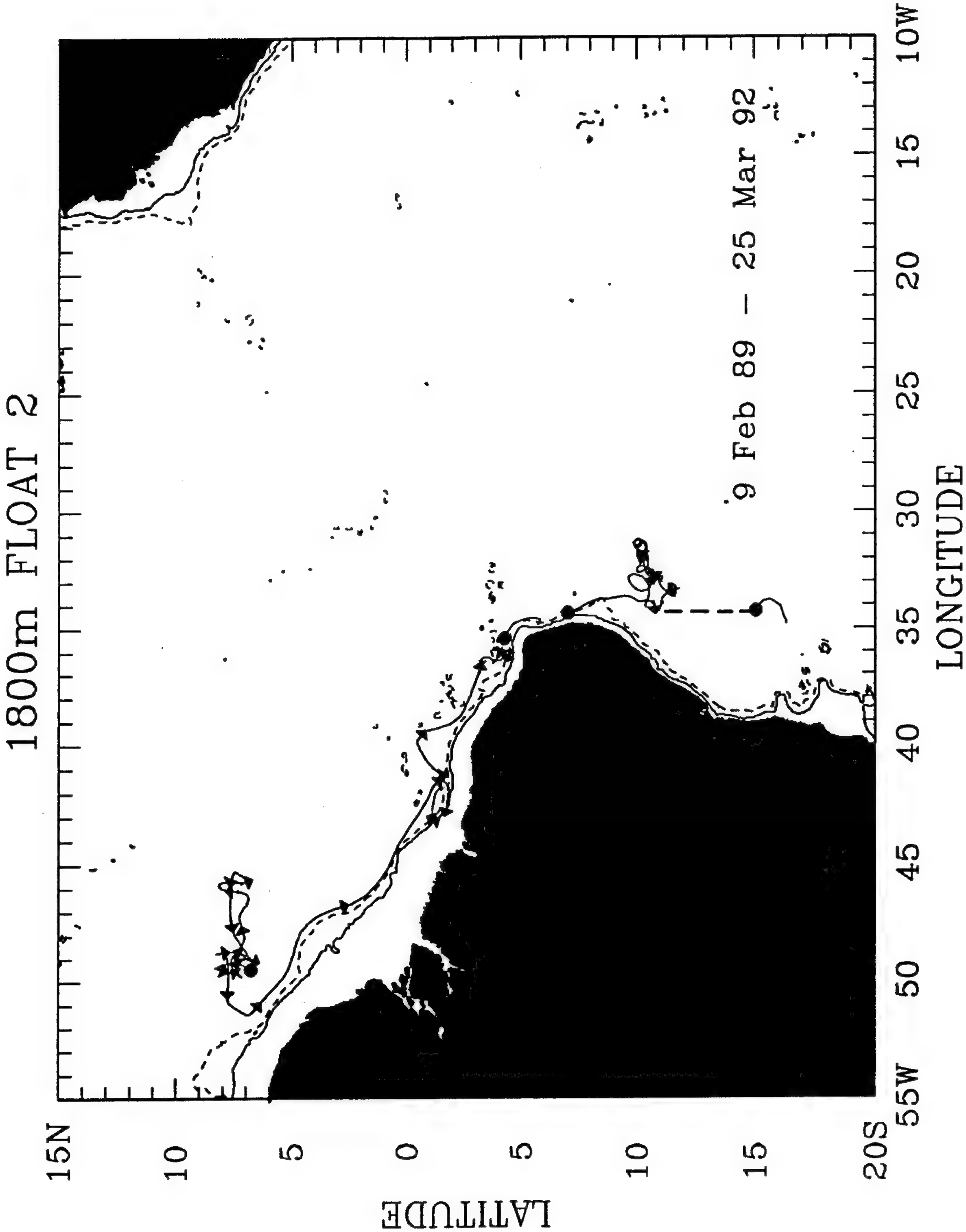

1800m FLOAT 1
27 Jan 89 - 20 Sept 92
LONGITUDE
LATITUDE
55W
50
45
40
35
30
25
20
15
10W
15N
10
5
0
5
10
15
20S

TROPICAL ATLANTIC 01

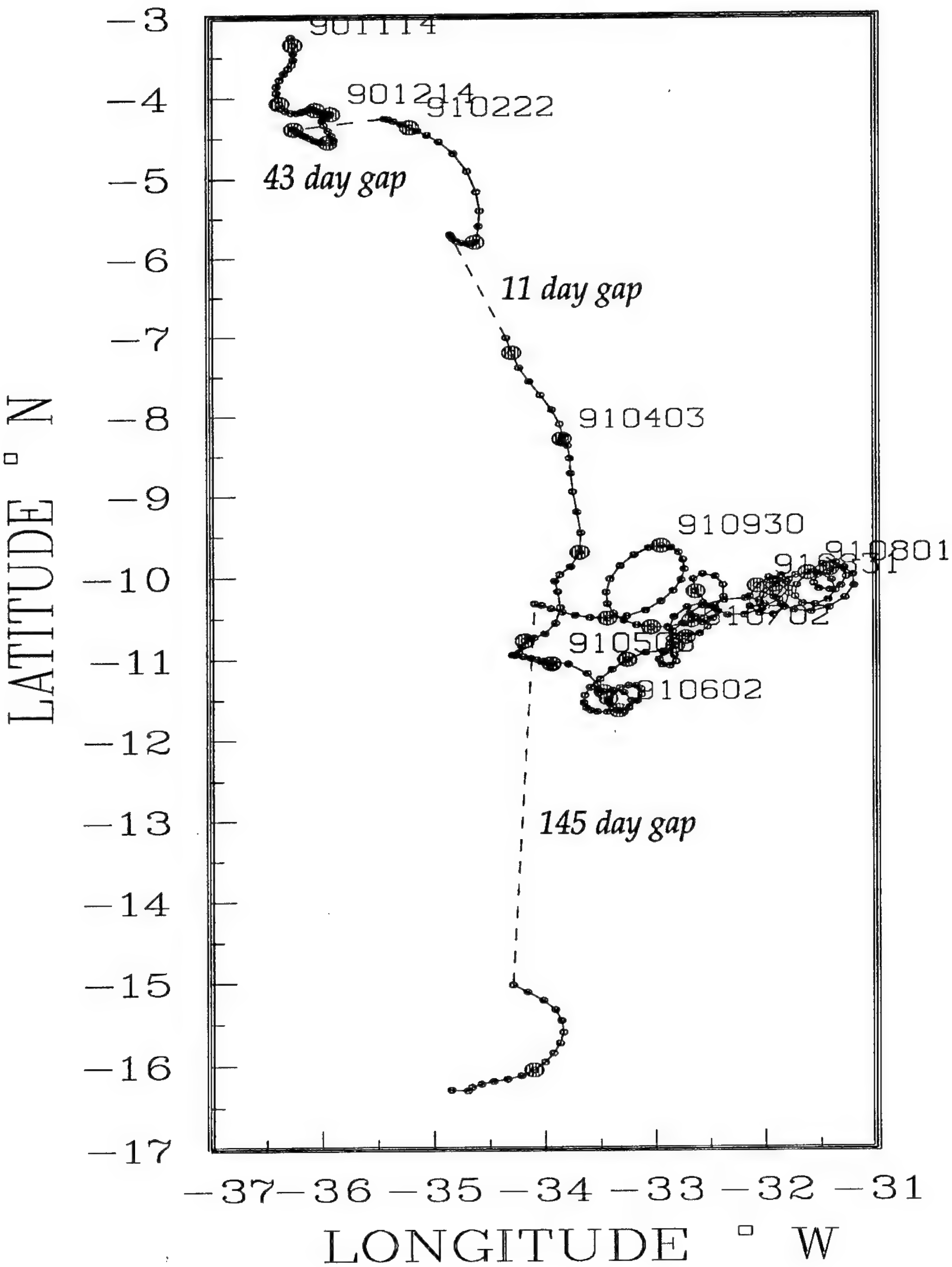


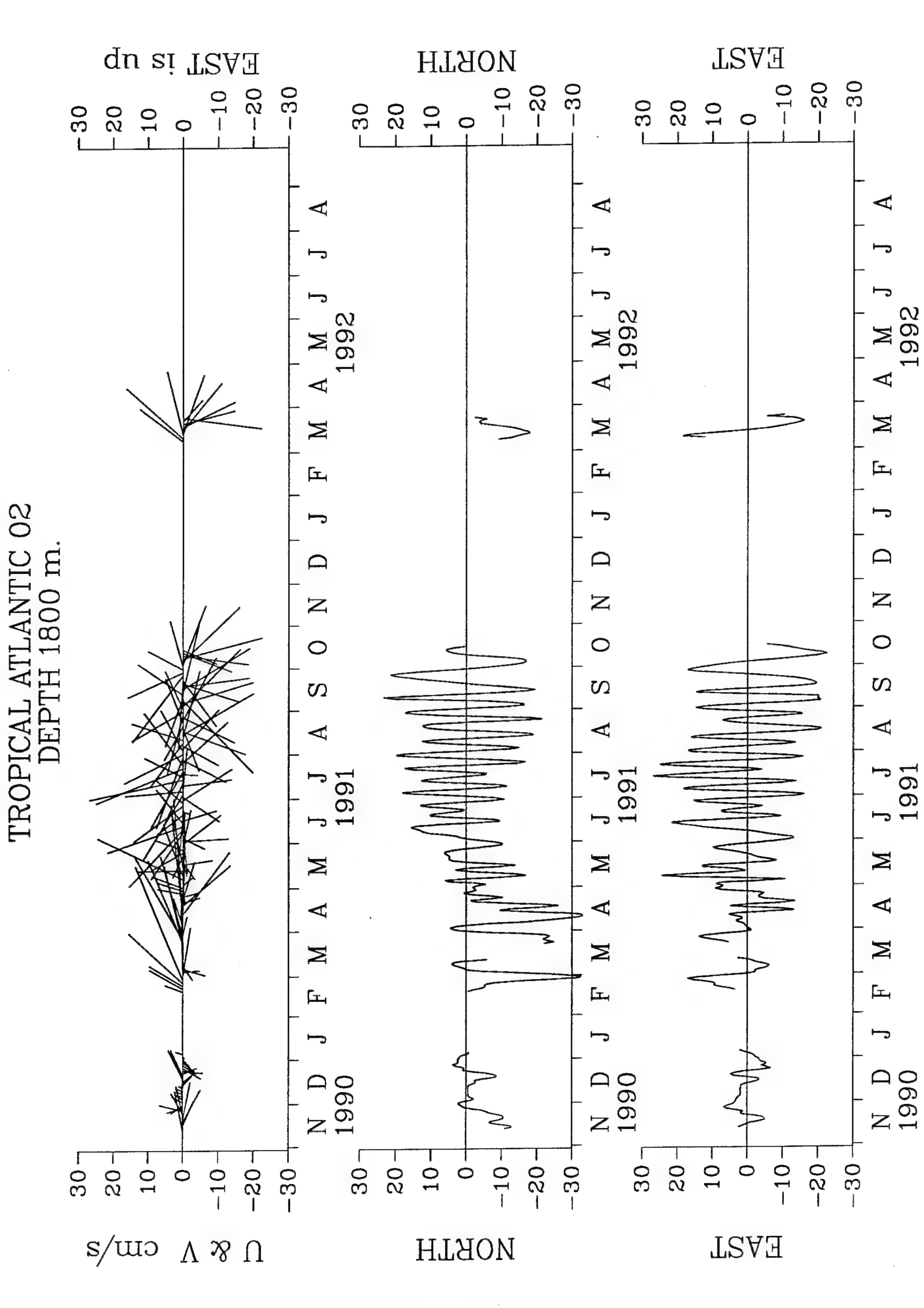
TROPICAL ATLANTIC 01
DEPTH 1800 m.

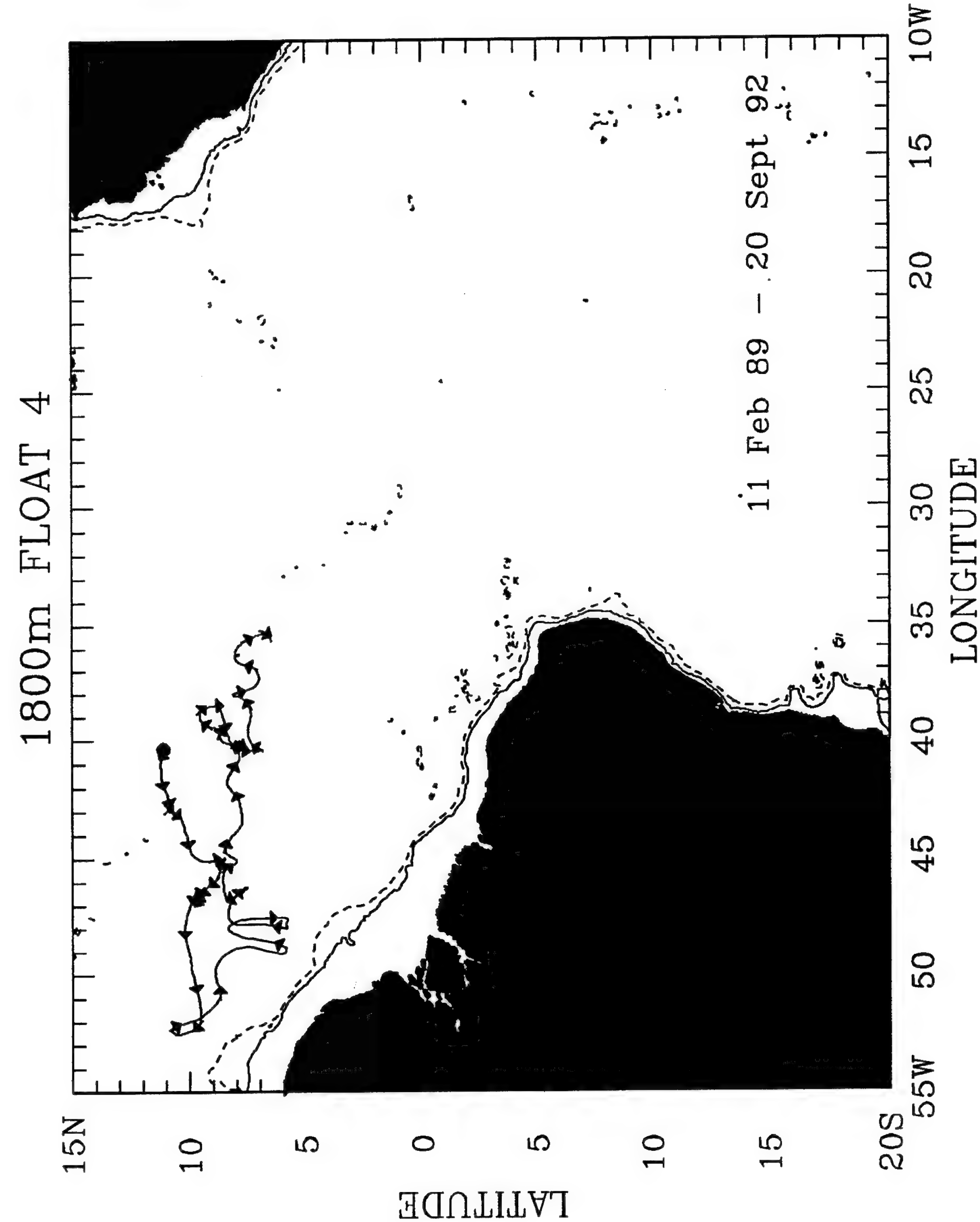



1800m FLOAT 2
9 Feb 89 — 25 Mar 92
LATITUDE
LONGITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

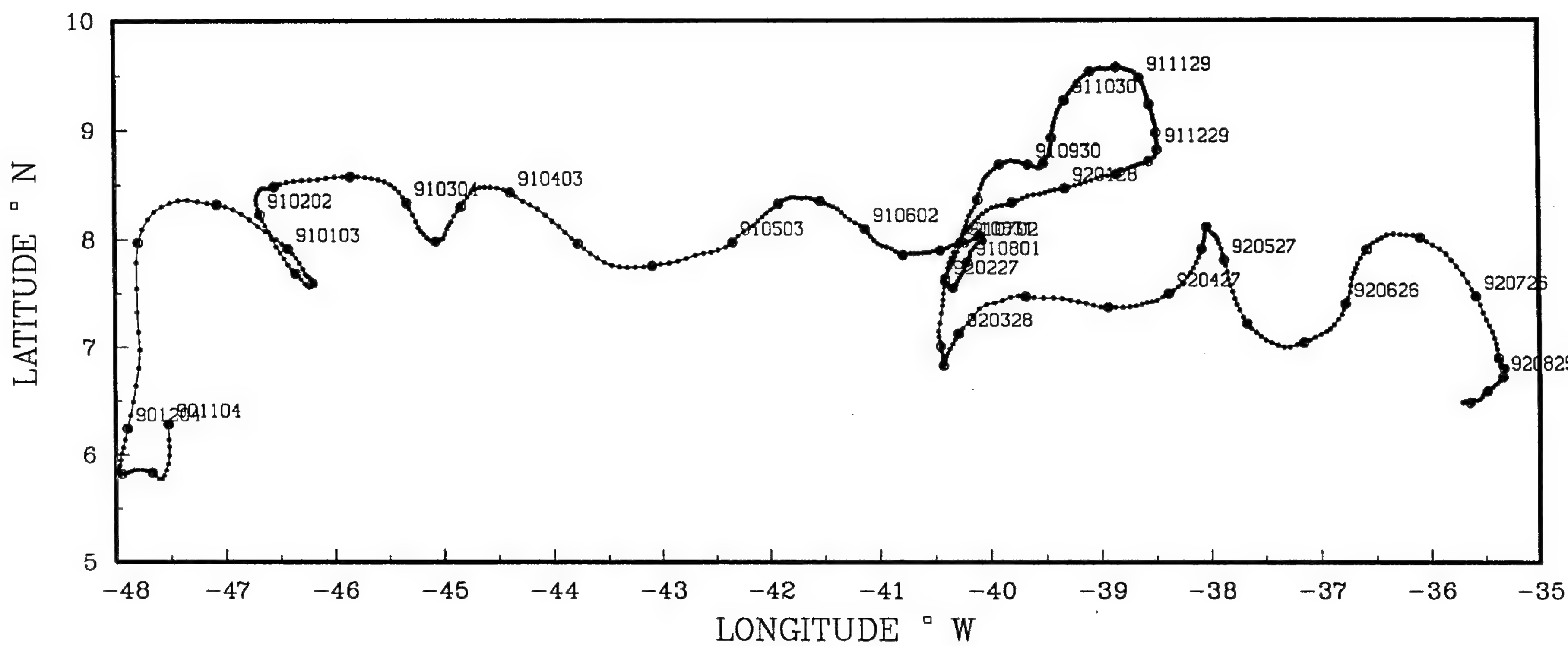
TROPICAL ATLANTIC 02



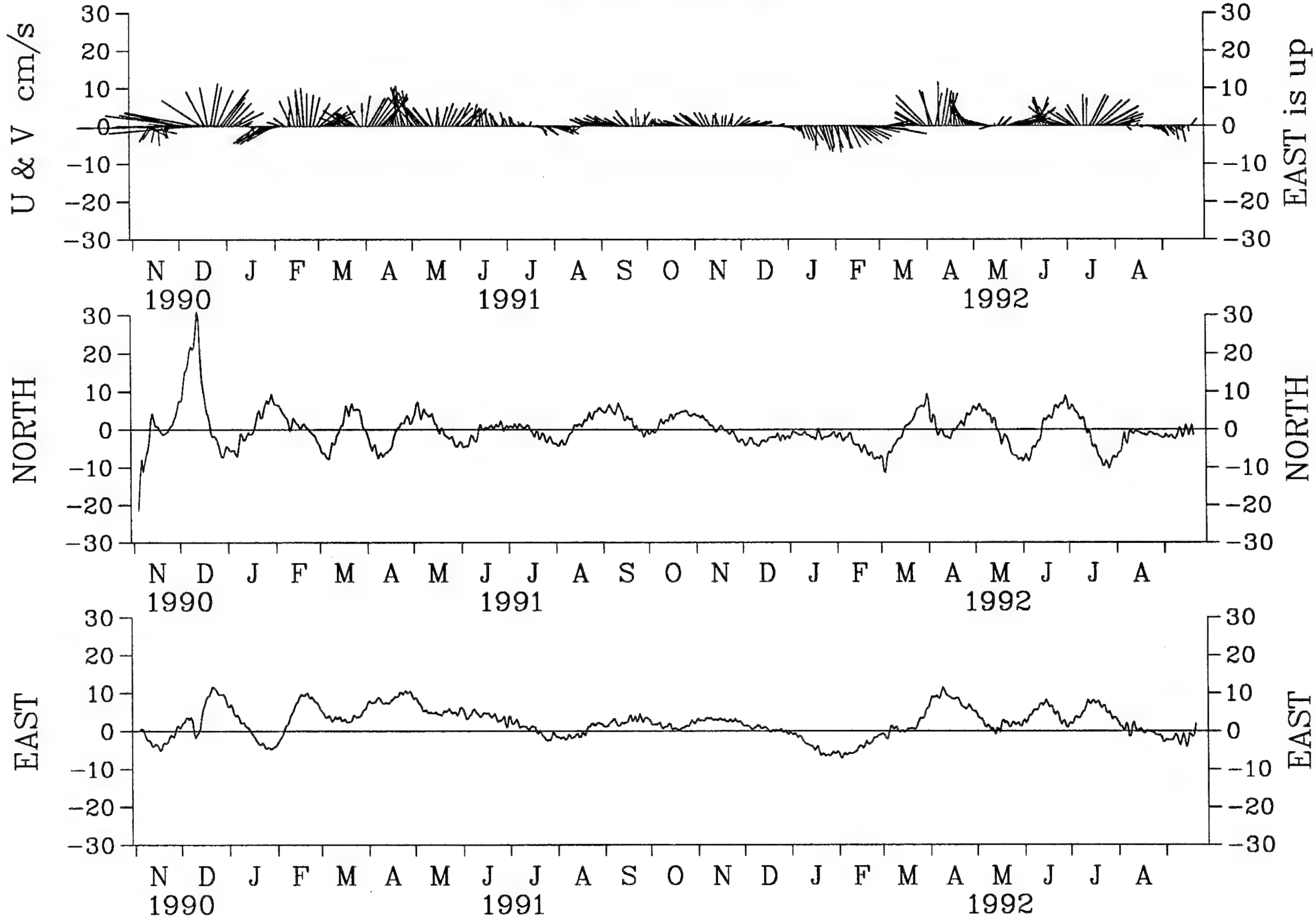

TROPICAL ATLANTIC 02
DEPTH 1800 m.
EAST is up
U & V cm/s
NORTH
EAST
30
20
10
0
−10
−20
−30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

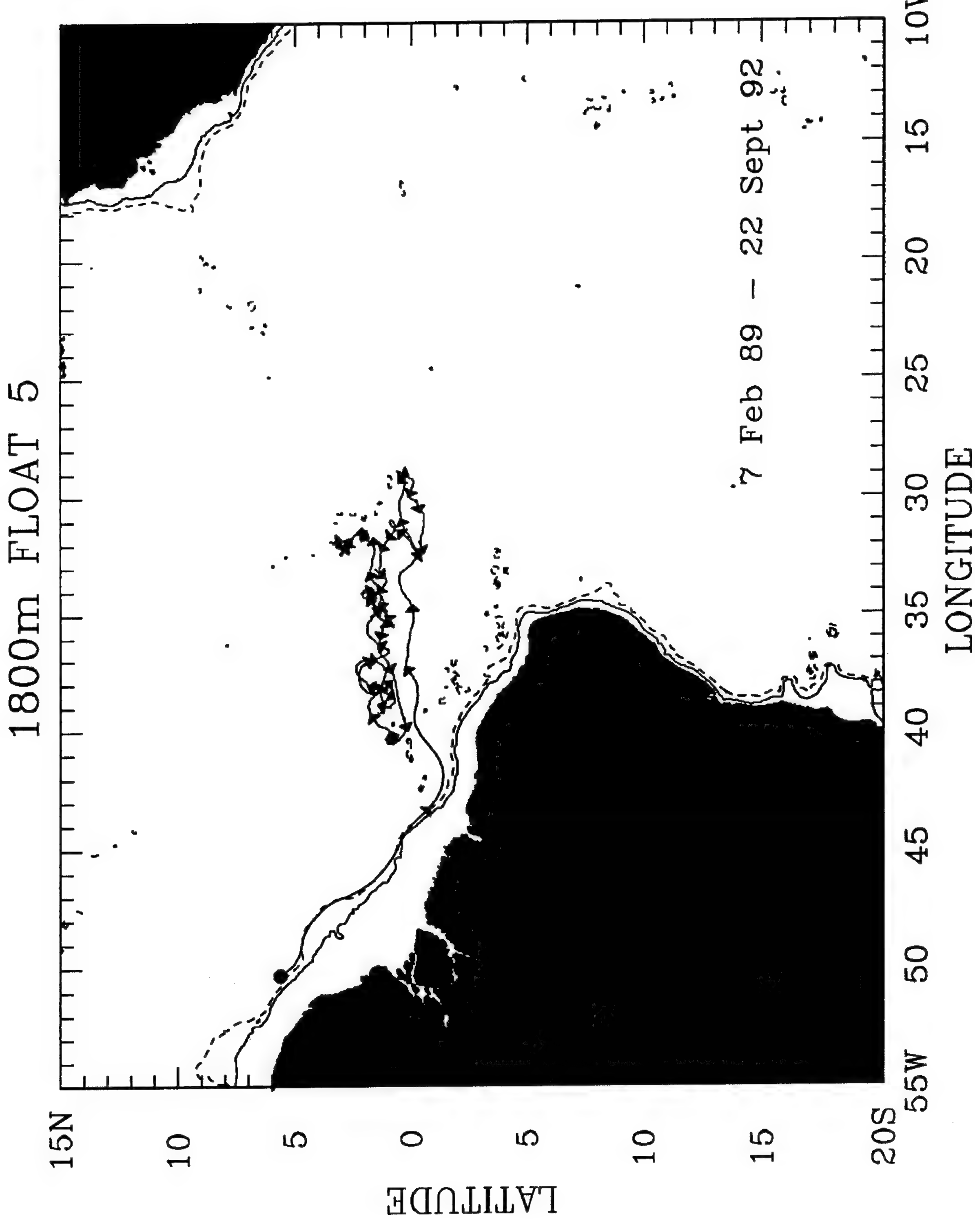

1800m FLOAT 4
11 Feb 89 – 20 Sept 92
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 04



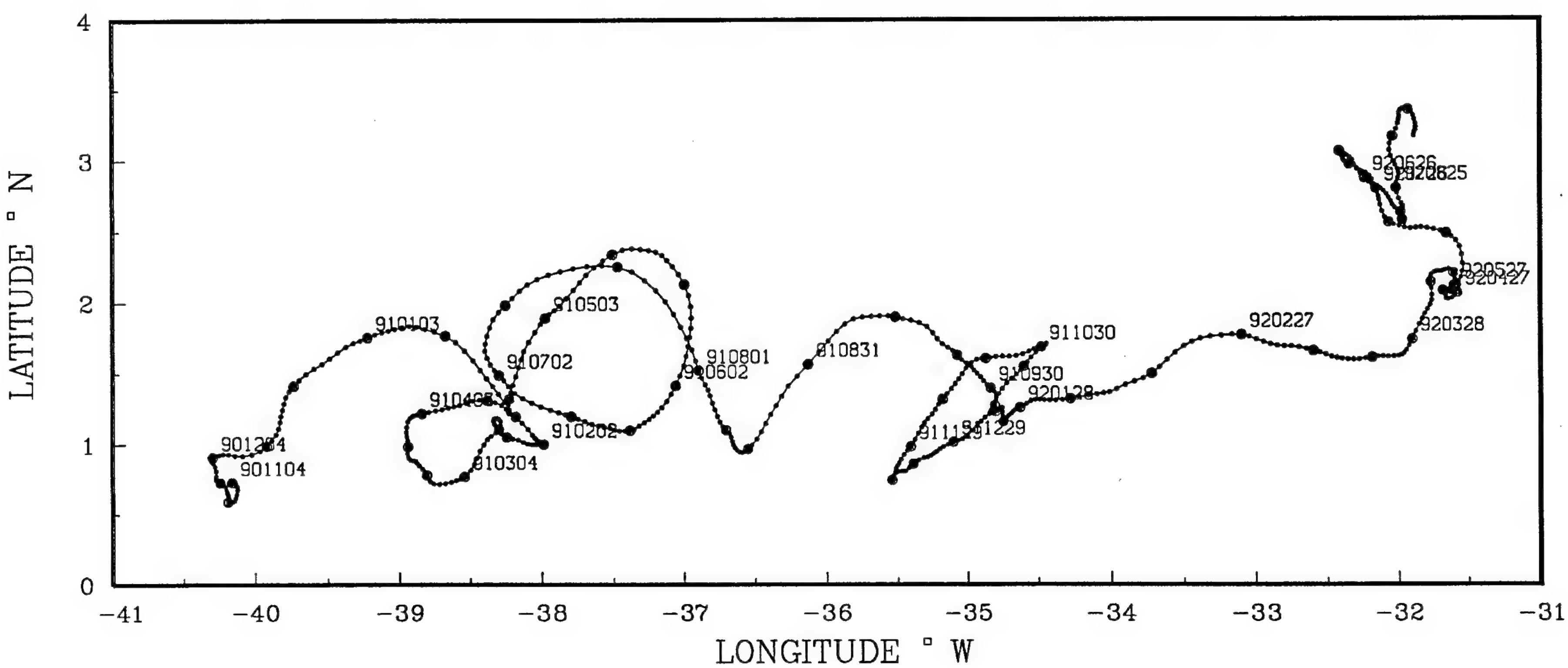
TROPICAL ATLANTIC 04
DEPTH 1800 m.

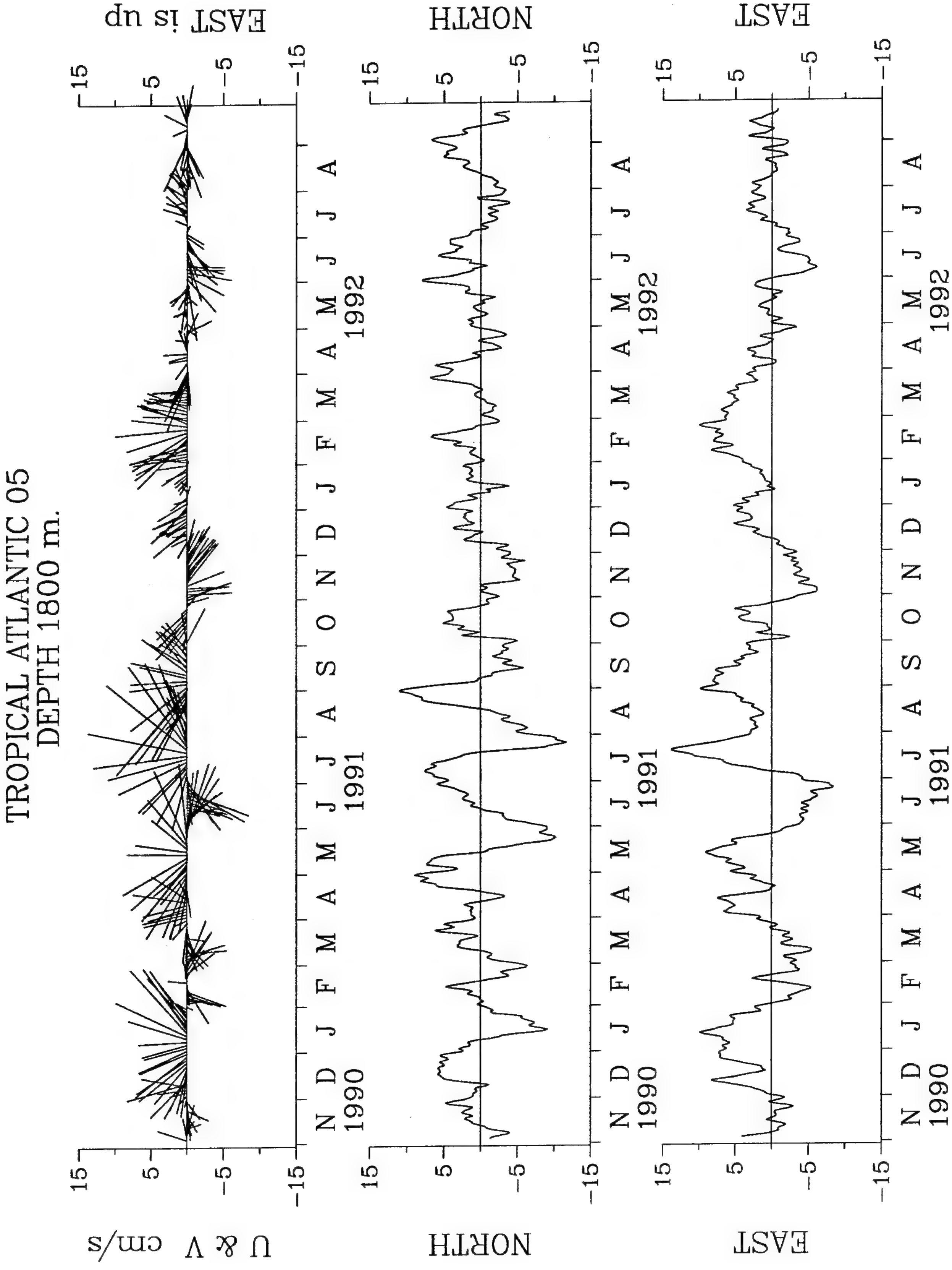




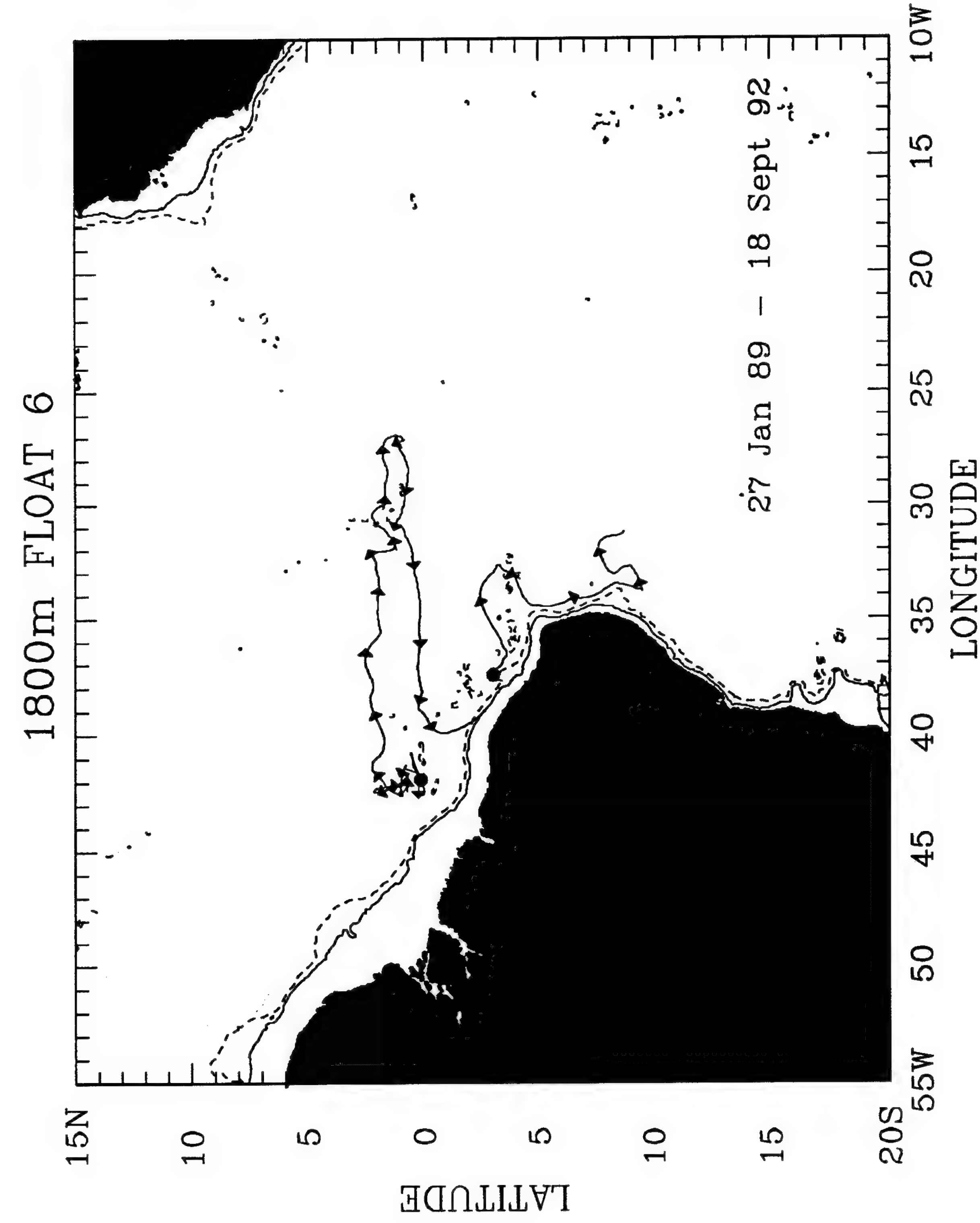
1800m FLOAT 5
7 Feb 89 – 22 Sept 92
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 05

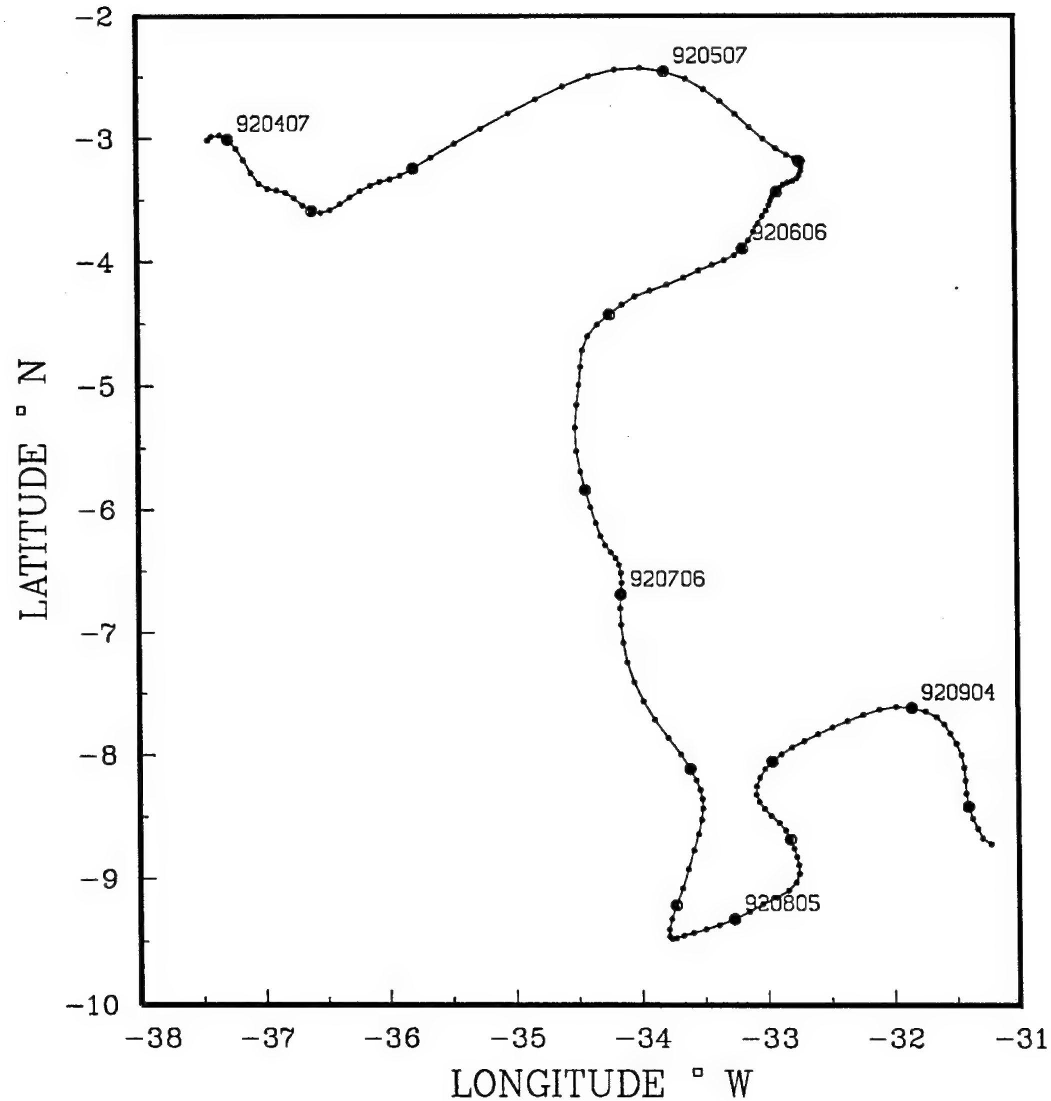


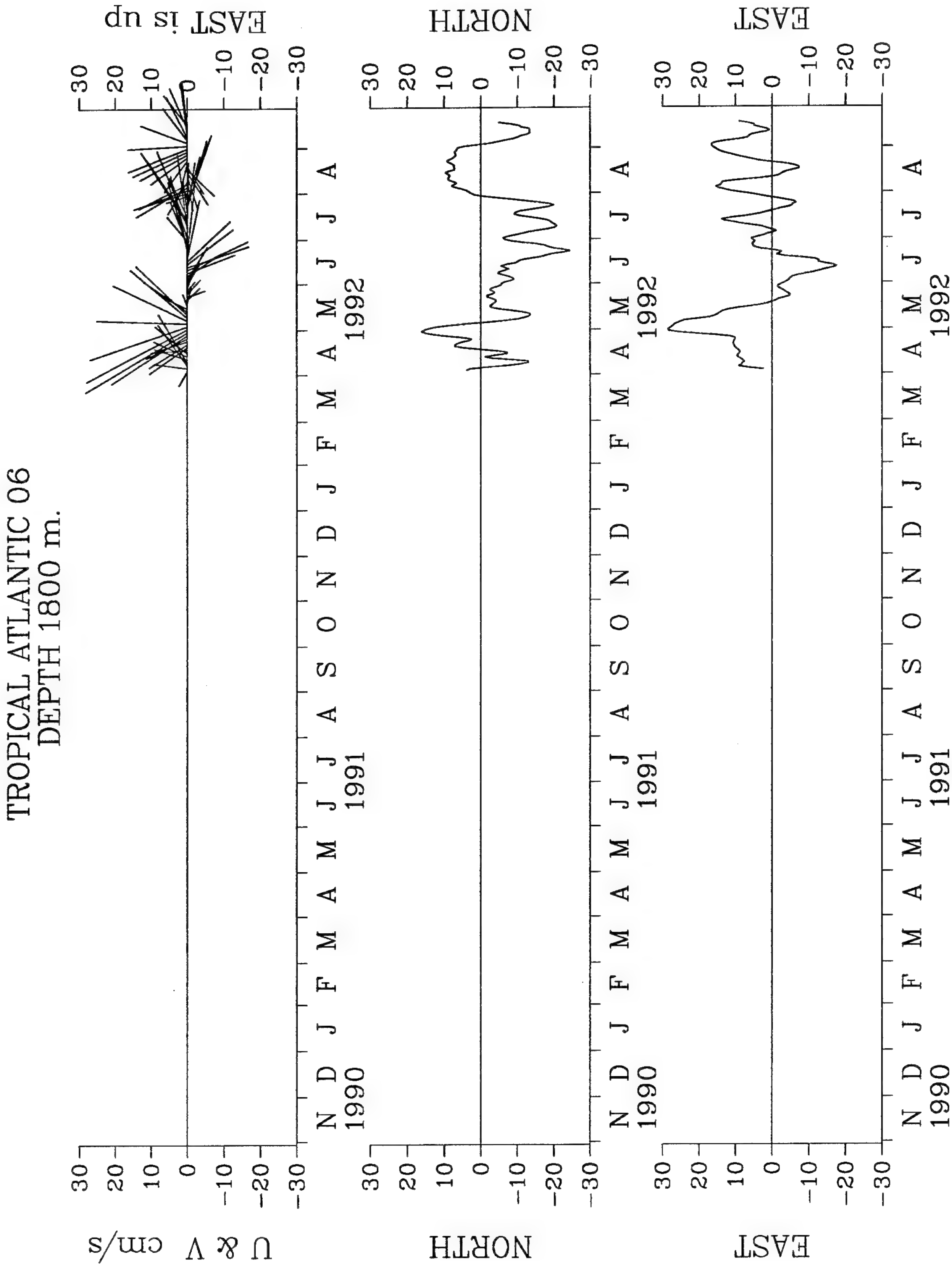


TROPICAL ATLANTIC 05
DEPTH 1800 m.
EAST is up
U & V cm/s
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

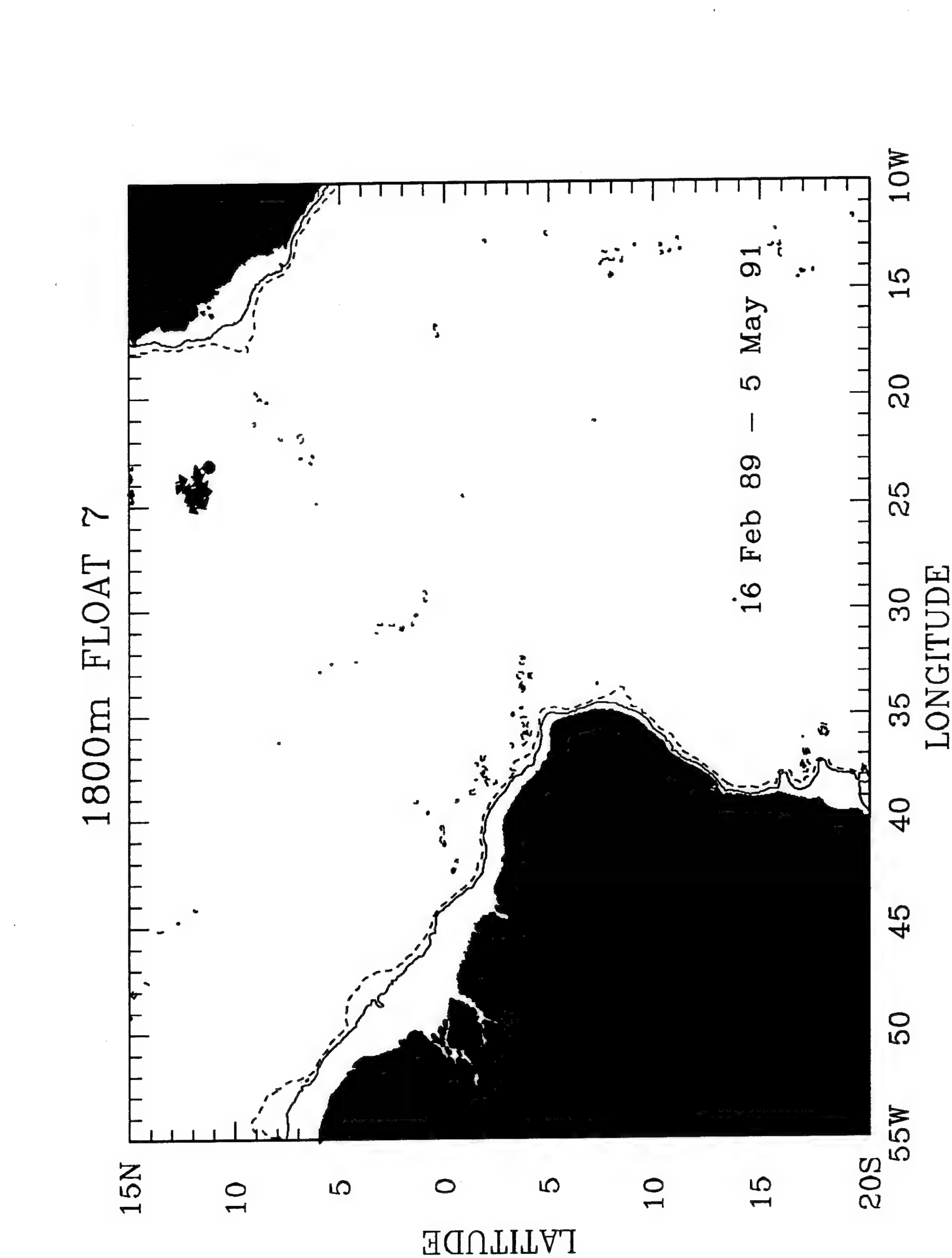

1800m FLOAT 6
27 Jan 89 – 18 Sept 92
LATITUDE
15N
10
5
0
5
10
15
20S
LONGITUDE
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 06

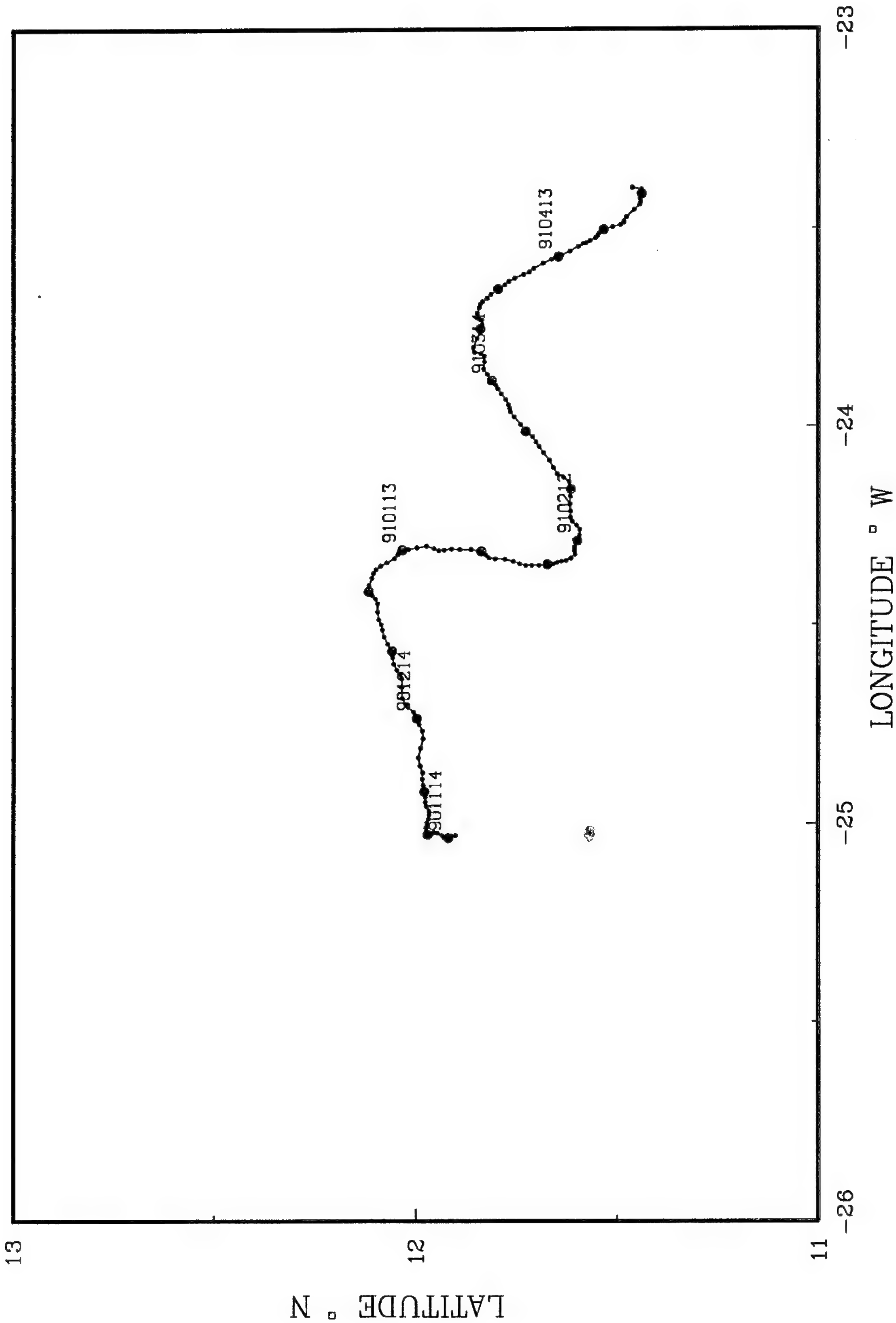




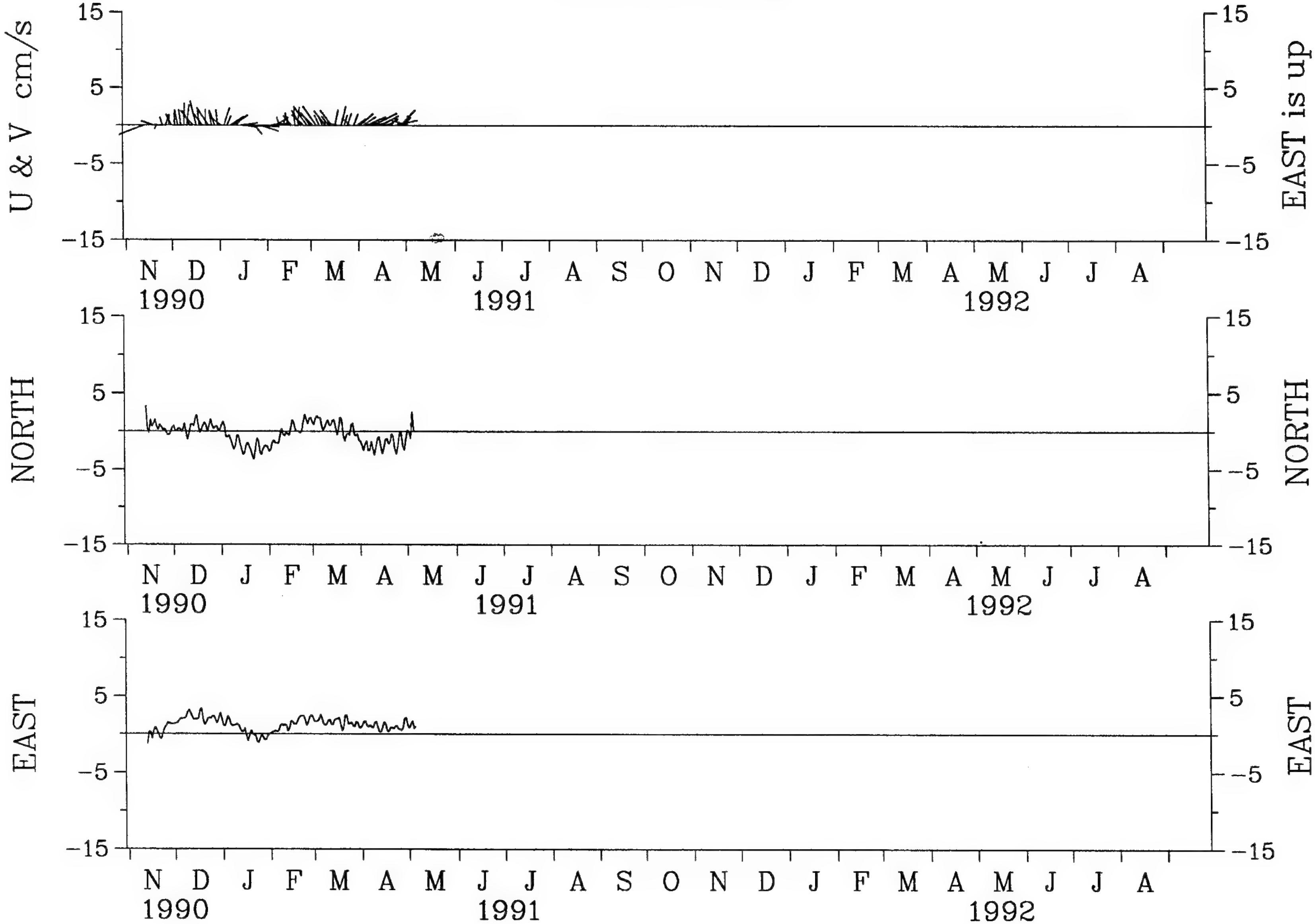
TROPICAL ATLANTIC 06
DEPTH 1800 m.
U & V cm/s
EAST is up
NORTH
EAST
30 20 10 0 −10 −20 −30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

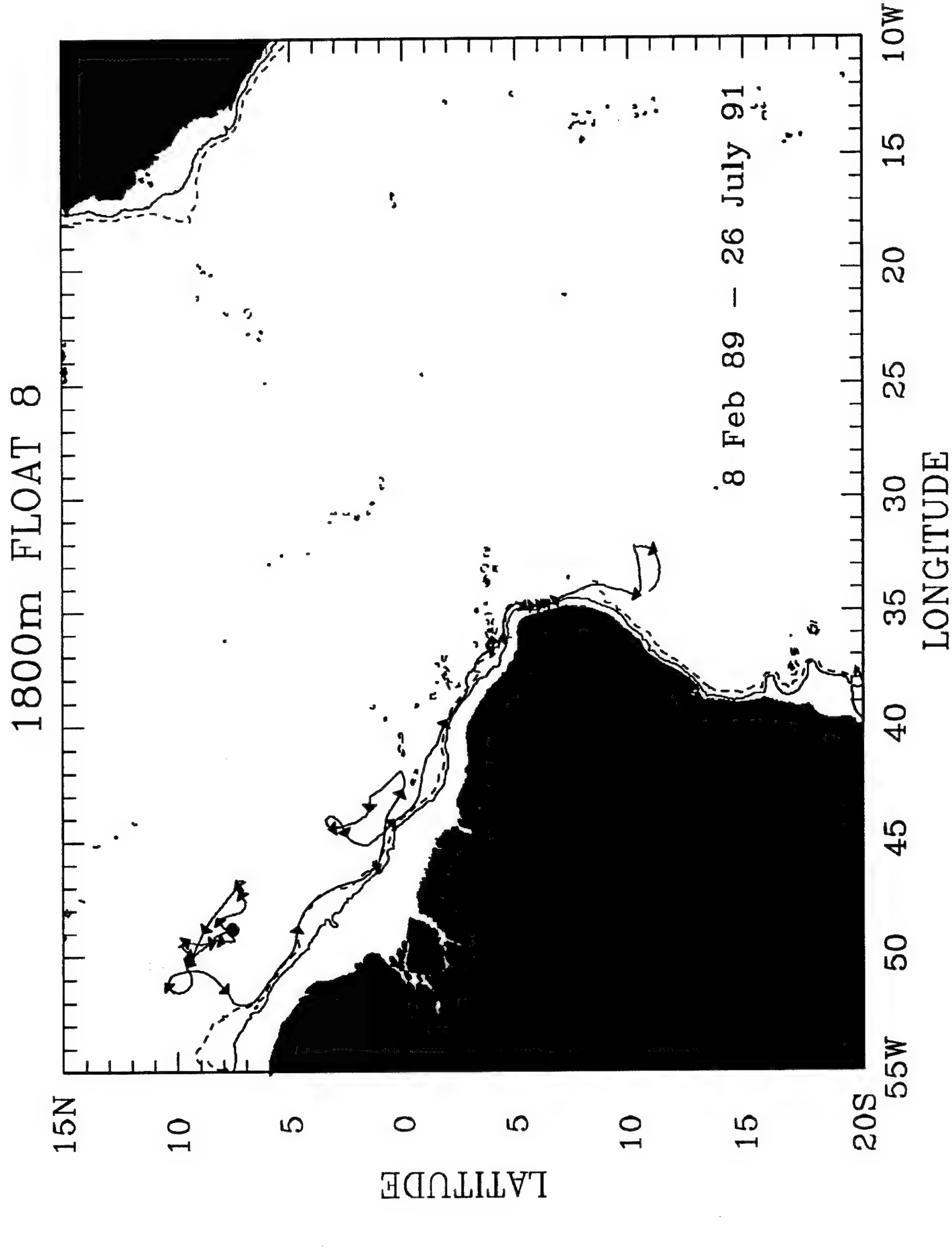

1800m FLOAT 7
16 Feb 89 – 5 May 91
LATITUDE
15N
10
5
0
5
10
15
20S
LONGITUDE
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 07



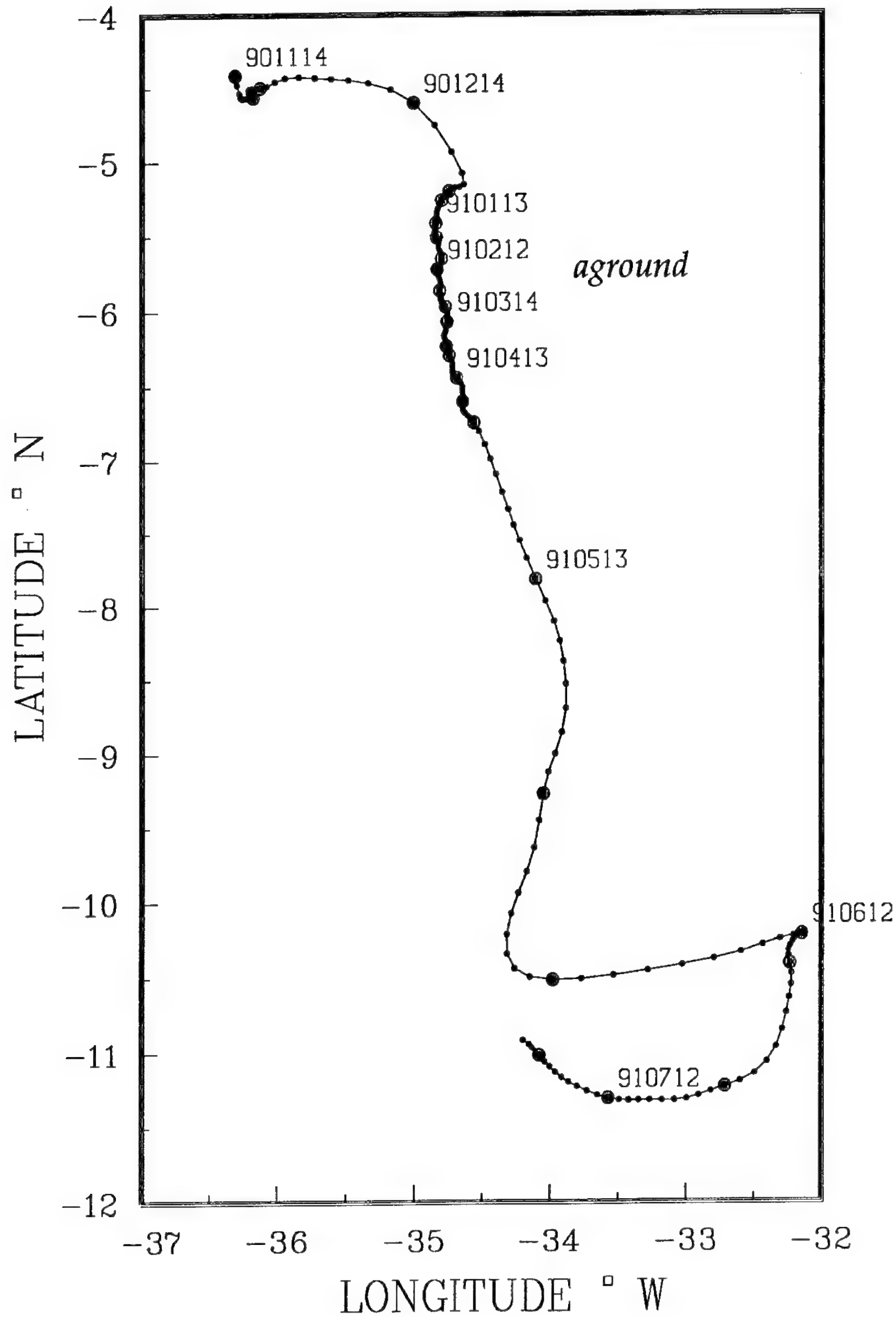
TROPICAL ATLANTIC 07
DEPTH 1800 m.

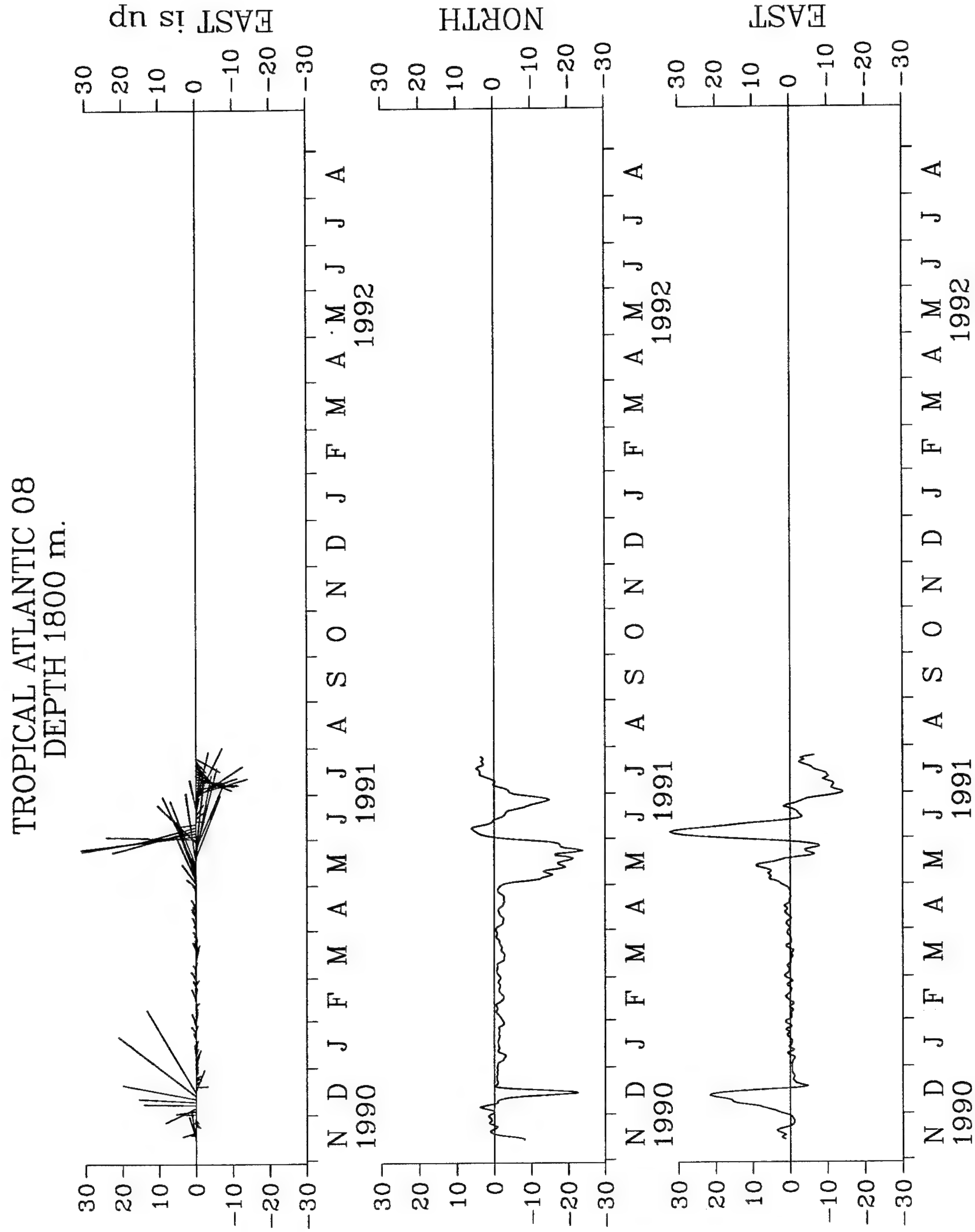


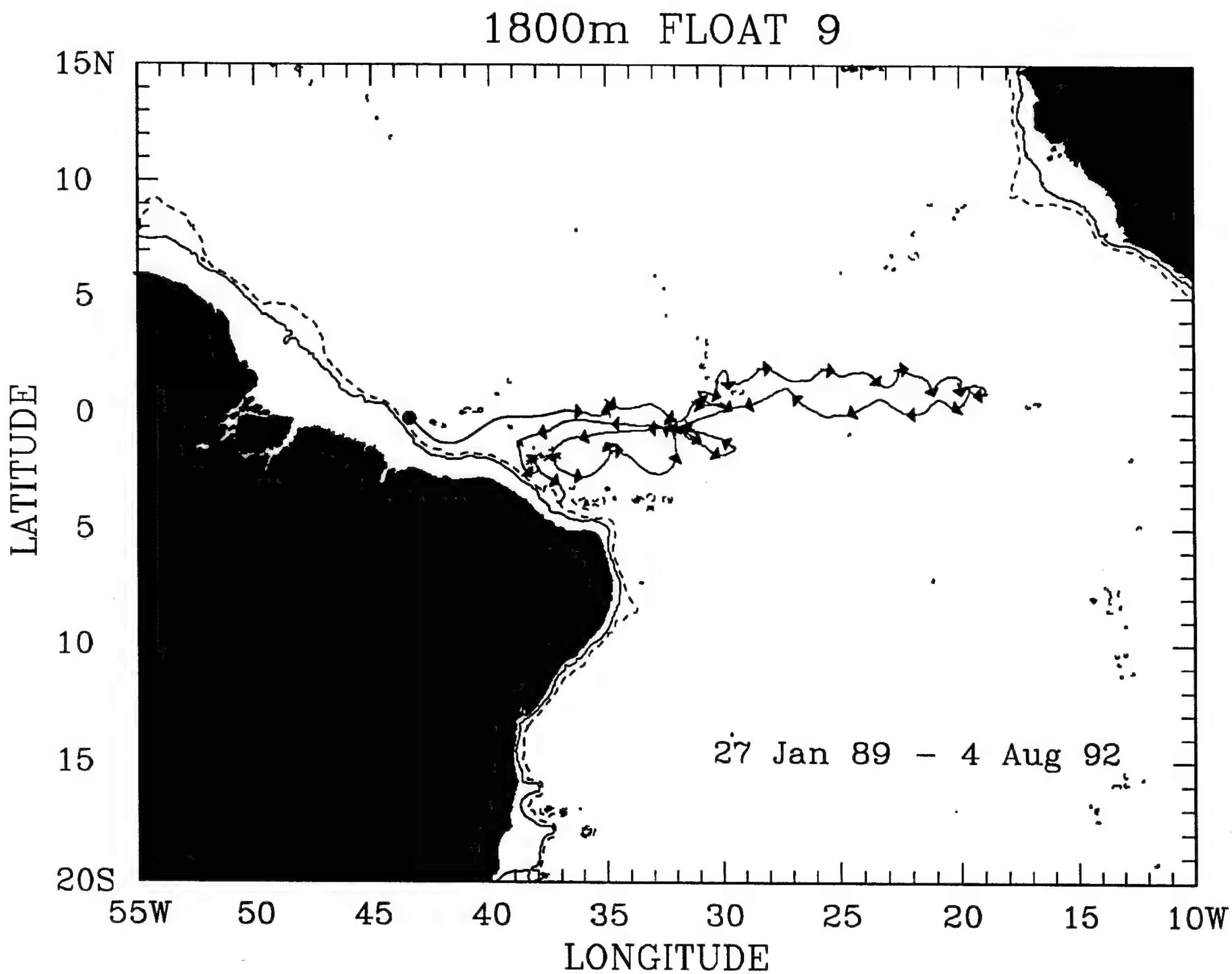


1800m FLOAT 8
8 Feb 89 – 26 July 91
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

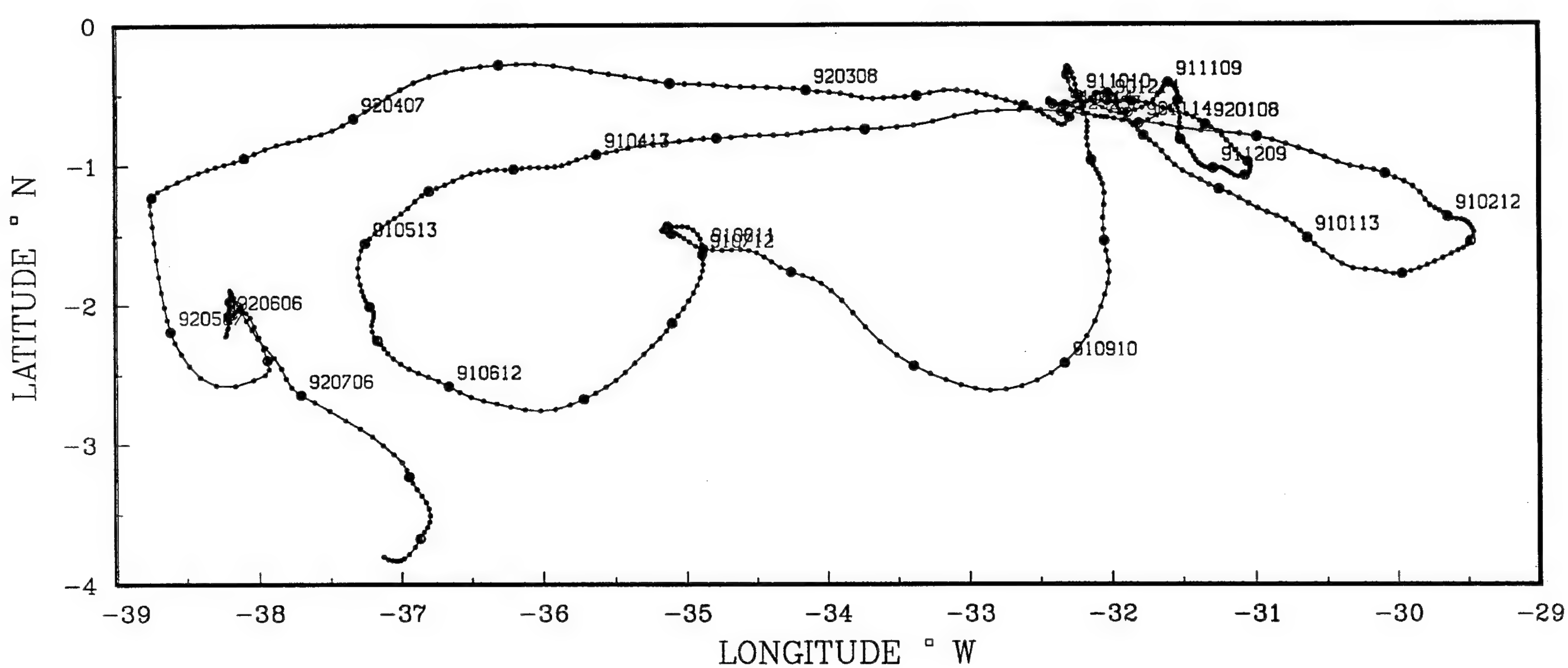
TROPICAL ATLANTIC 08

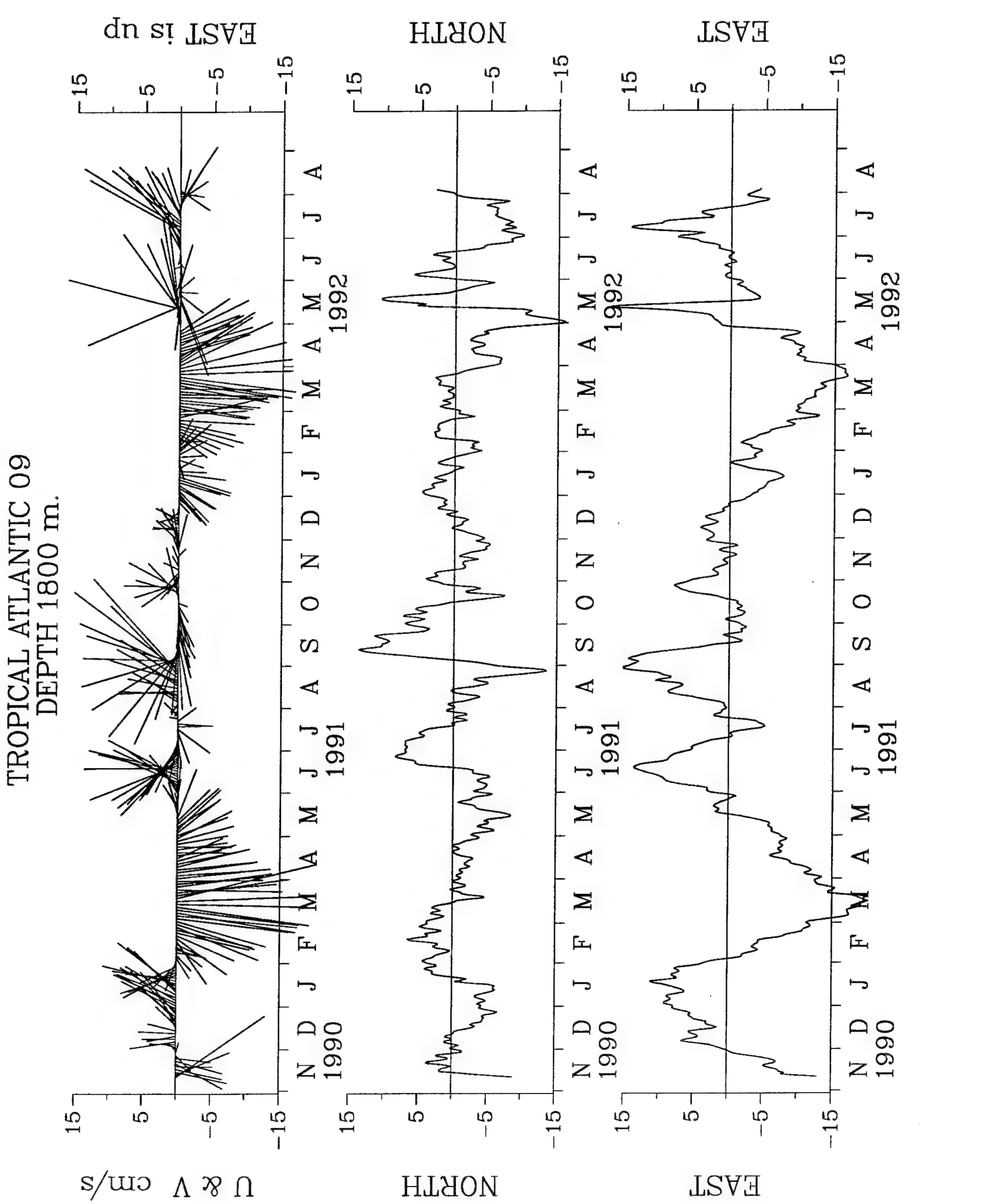


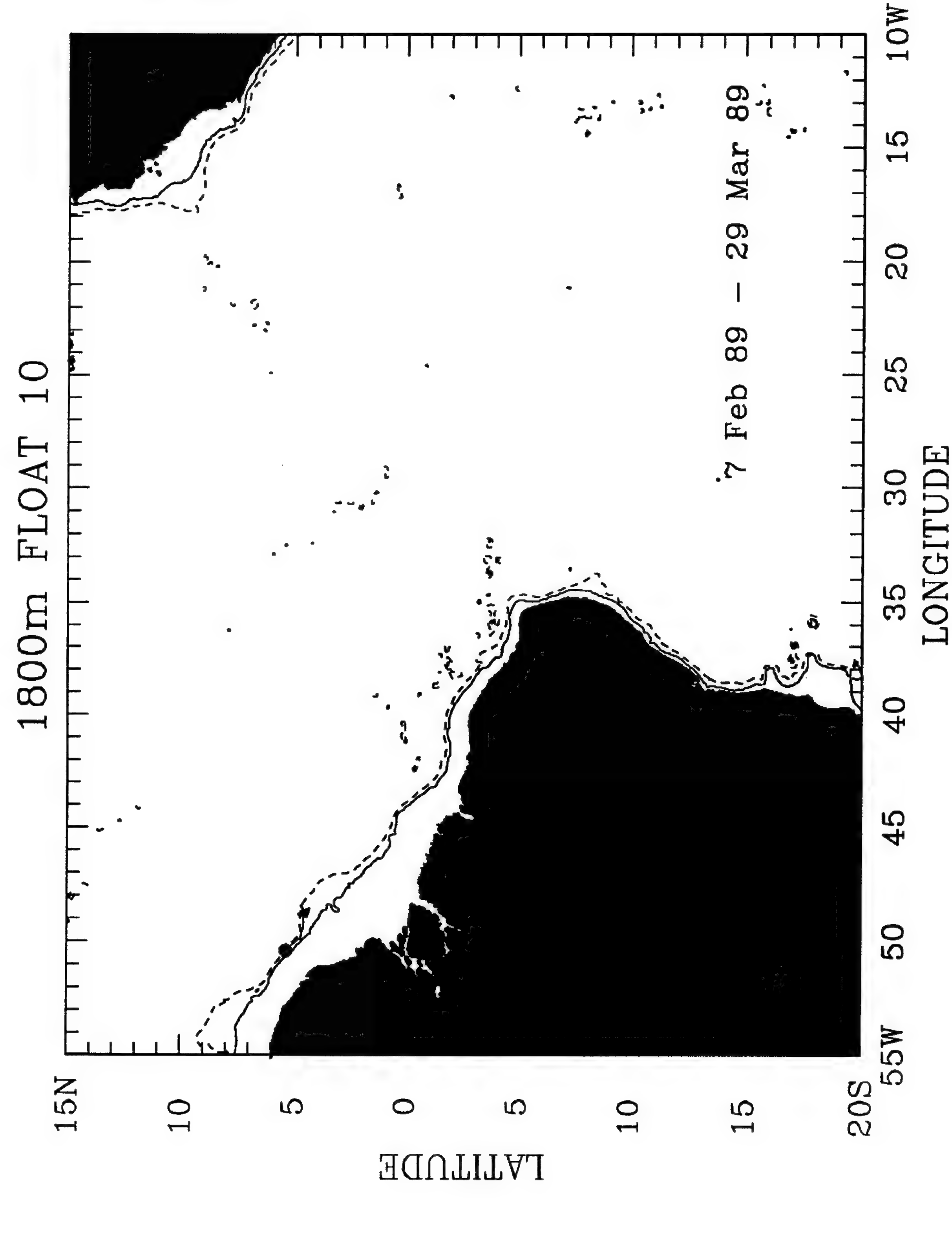

TROPICAL ATLANTIC 08
DEPTH 1800 m.
EAST is up
U & V cm/s
NORTH
EAST
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992
30 20 10 0 −10 −20 −30


1800m FLOAT 9
15N
10
5
0
5
10
15
20S
LATITUDE
55W
50
45
40
35
30
25
20
15
10W
LONGITUDE
27 Jan 89 – 4 Aug 92

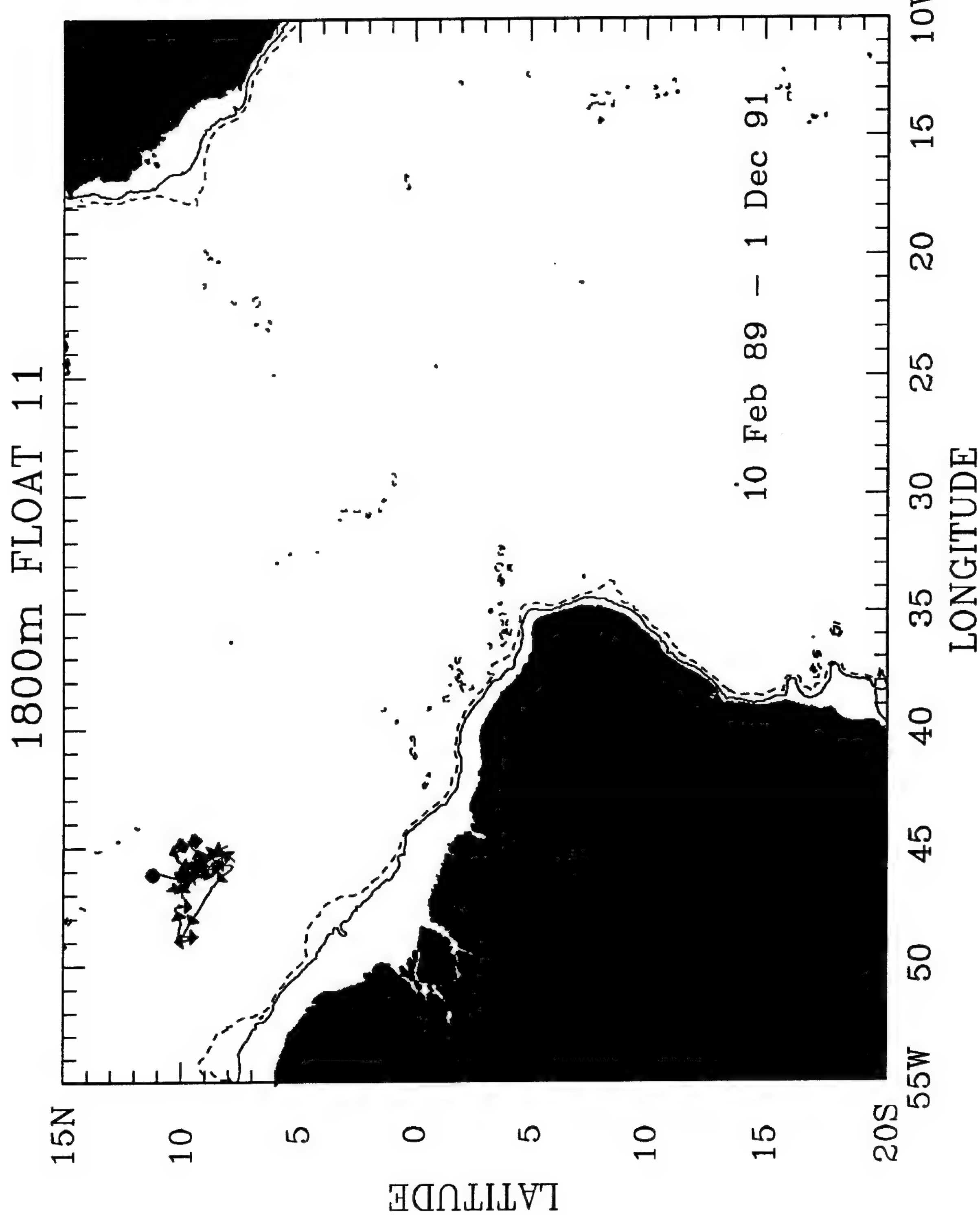
TROPICAL ATLANTIC 09



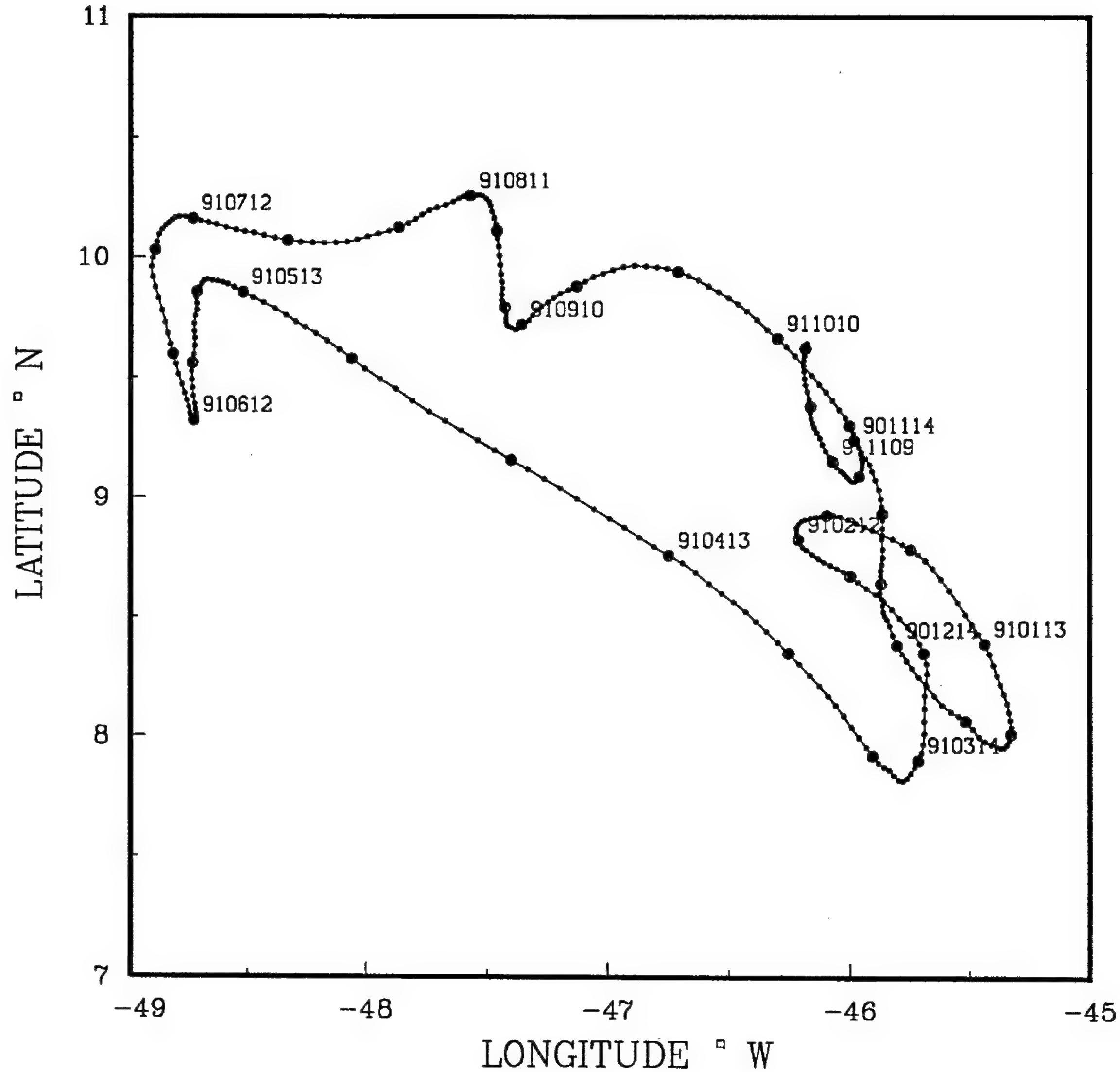

TROPICAL ATLANTIC 09
DEPTH 1800 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

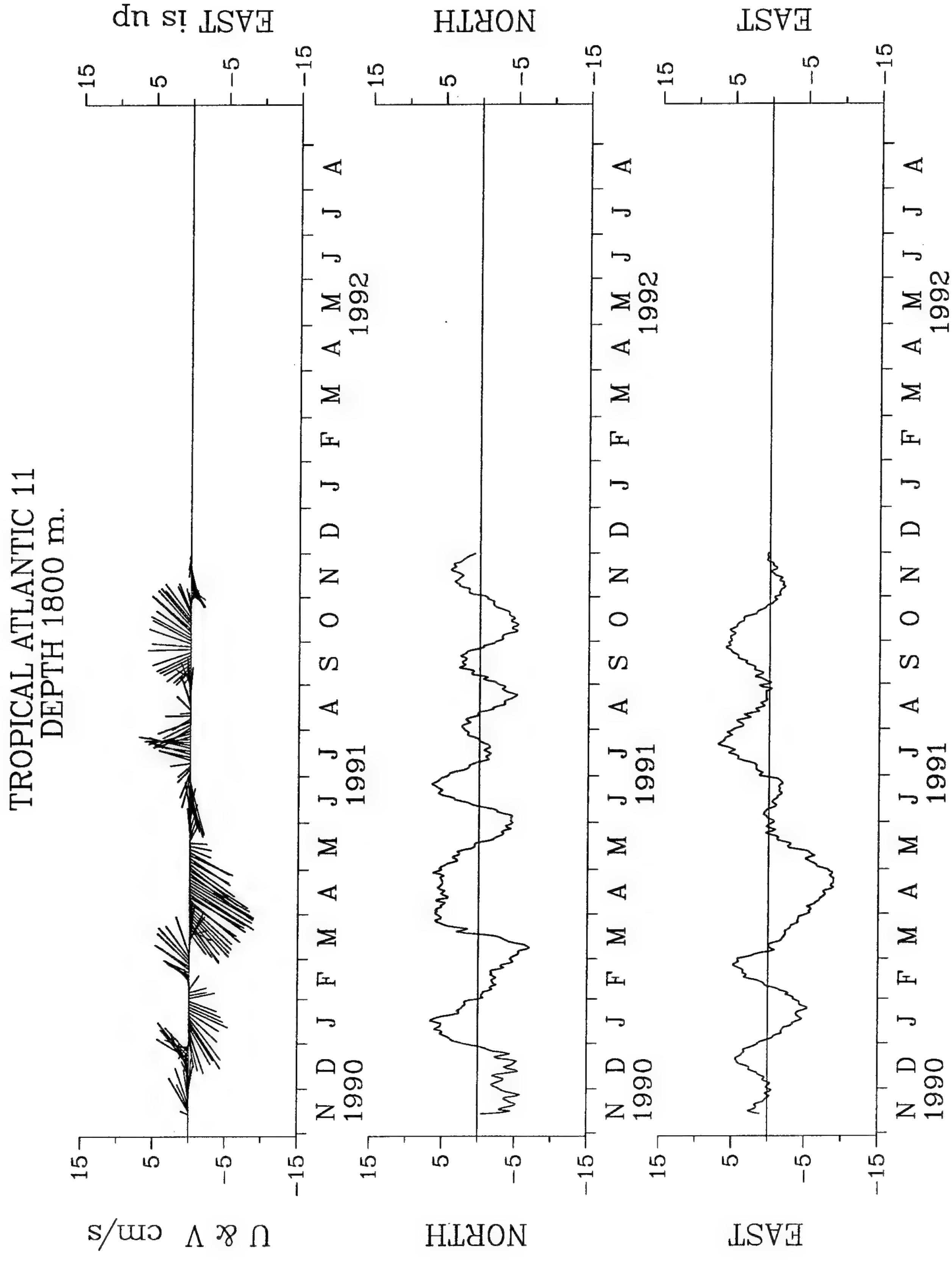


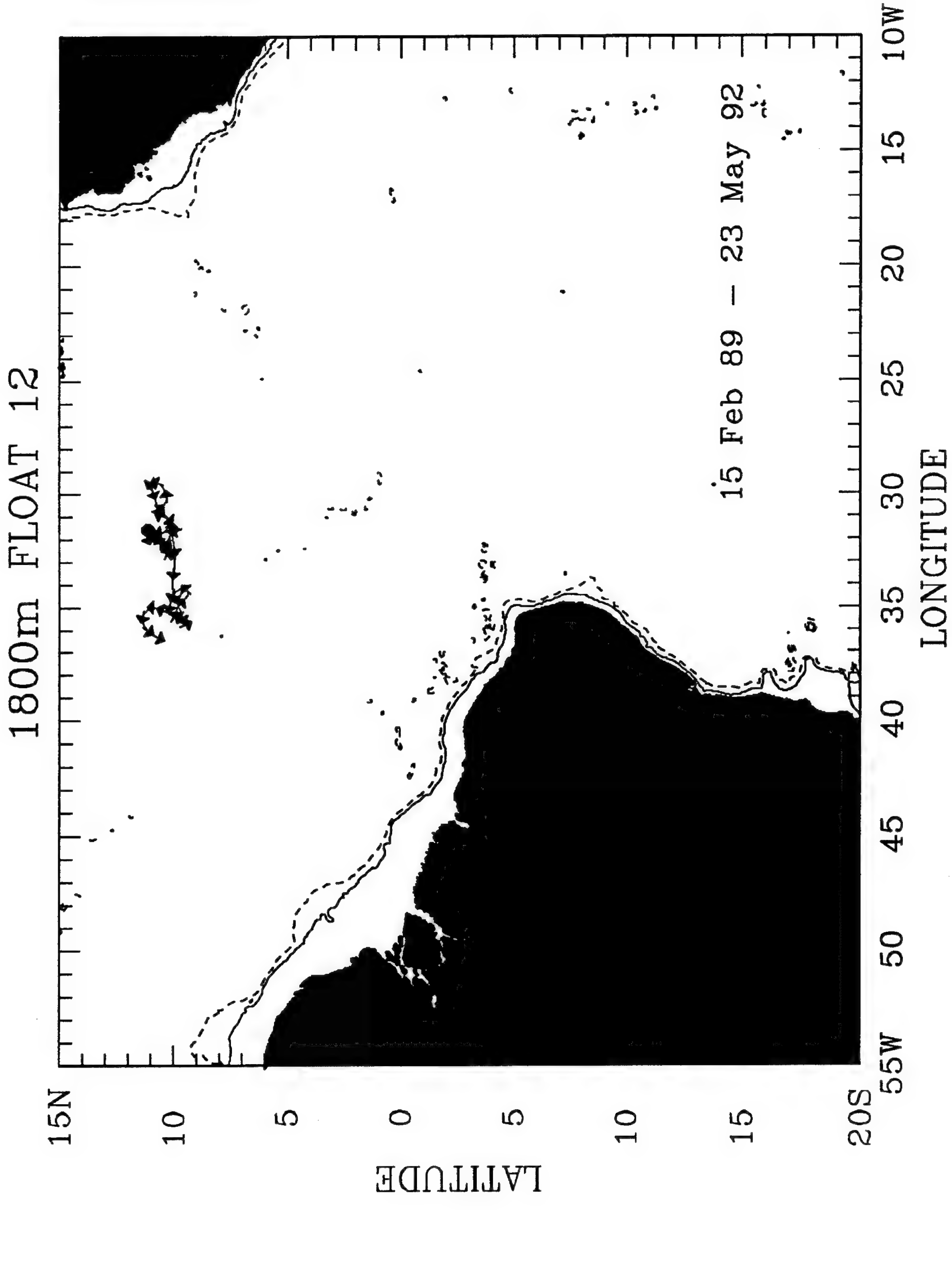
1800m FLOAT 10
7 Feb 89 - 29 Mar 89
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W


1800m FLOAT 11
10 Feb 89 – 1 Dec 91
LATITUDE
15N
10
5
0
5
10
15
20S
LONGITUDE
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 11

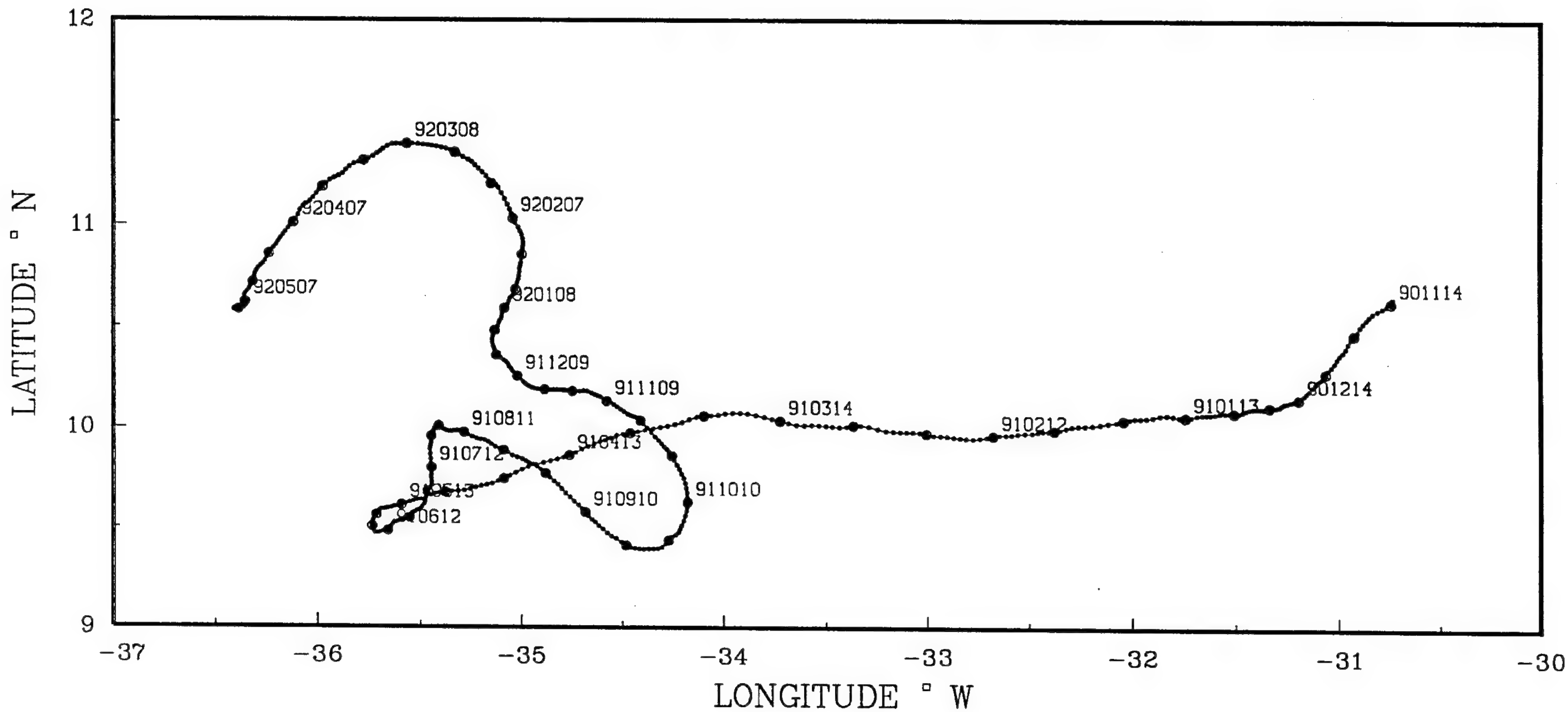


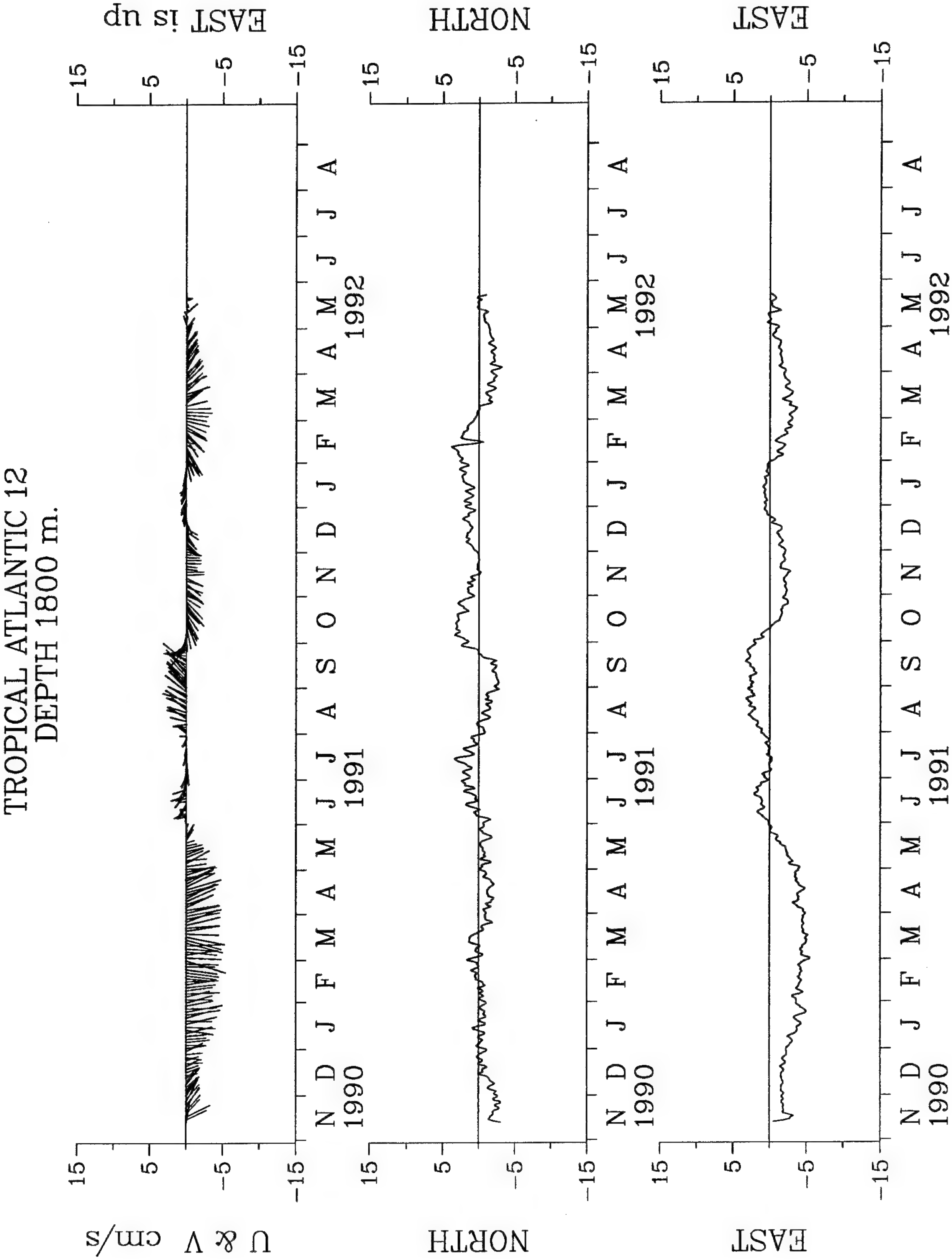

TROPICAL ATLANTIC 11
DEPTH 1800 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
−5
−15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

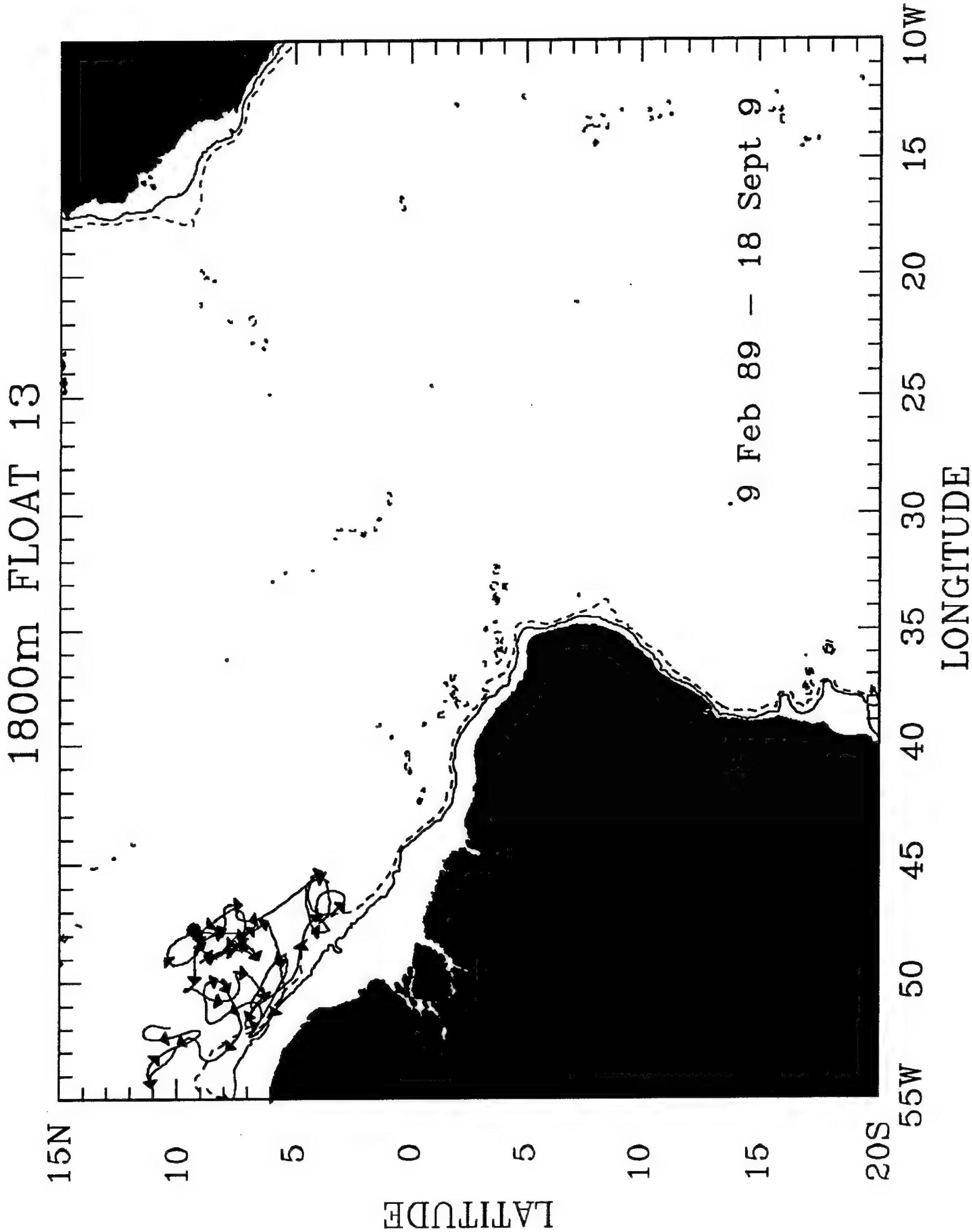


1800m FLOAT 12
15 Feb 89 – 23 May 92
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

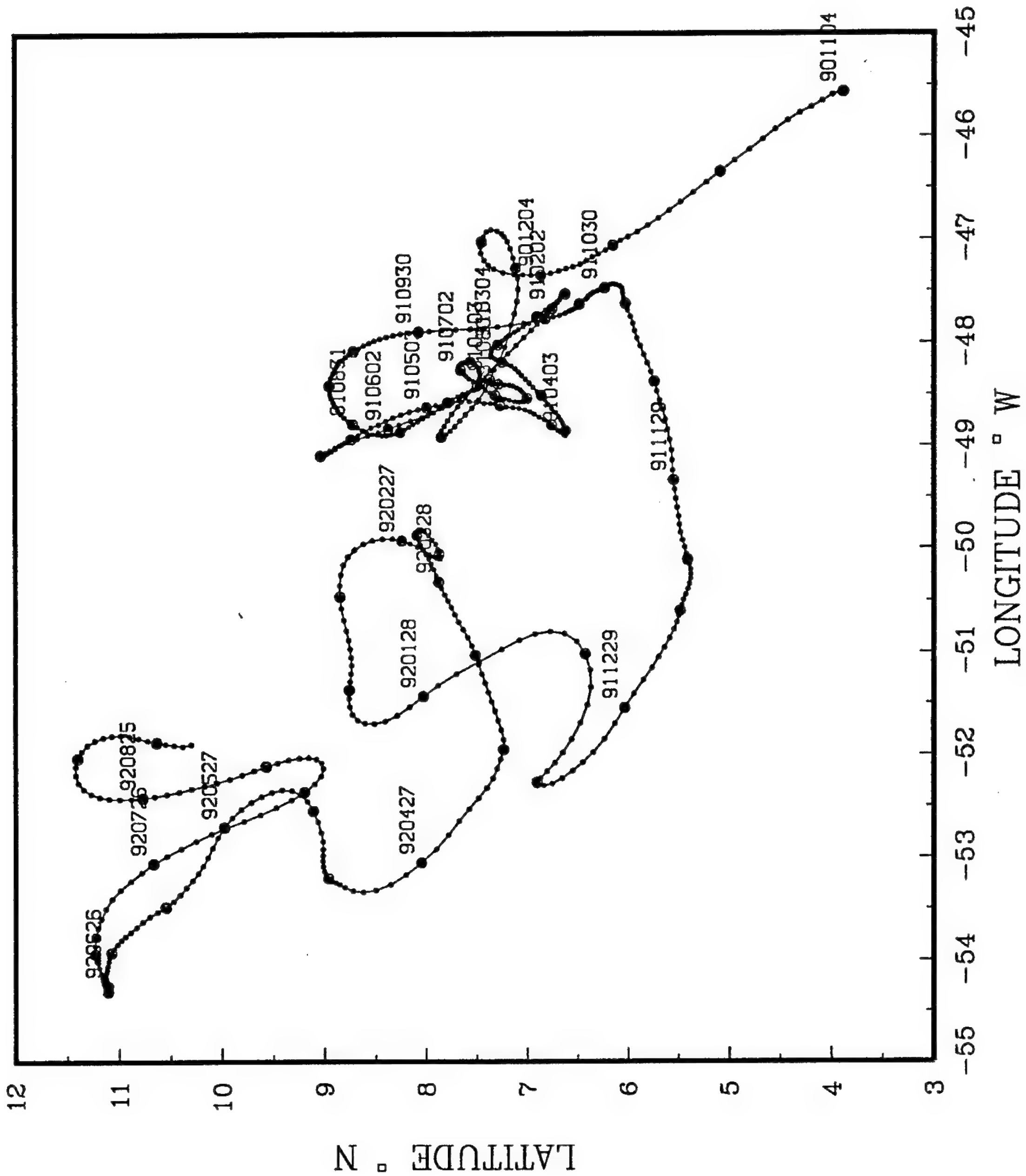
TROPICAL ATLANTIC 12

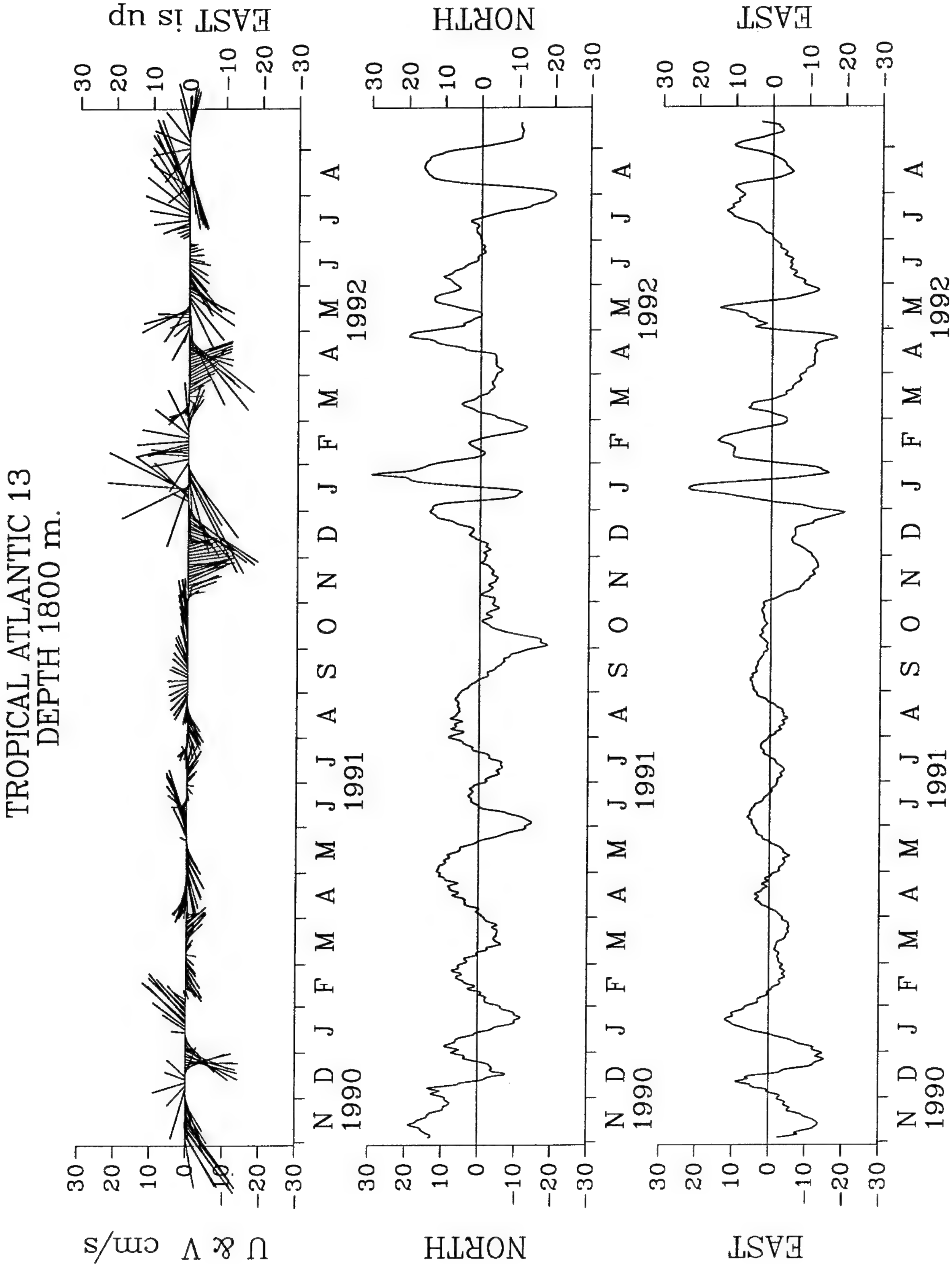



TROPICAL ATLANTIC 12
DEPTH 1800 m.
EAST is up
U & V cm/s
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

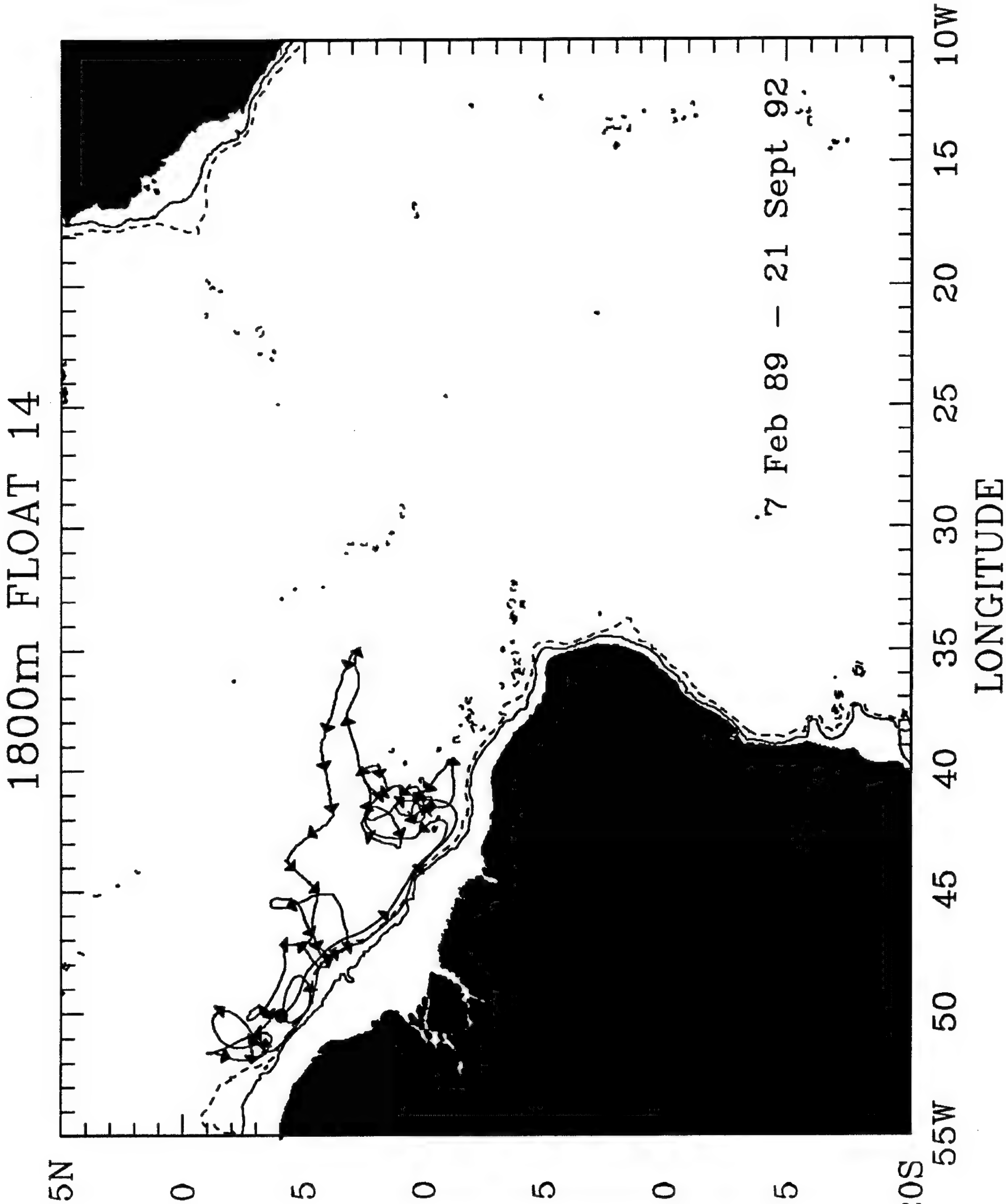

1800m FLOAT 13
9 Feb 89 — 18 Sept 9
LONGITUDE
55W
50
45
40
35
30
25
20
15
10W
LATITUDE
15N
10
5
0
5
10
15
20S

TROPICAL ATLANTIC 13

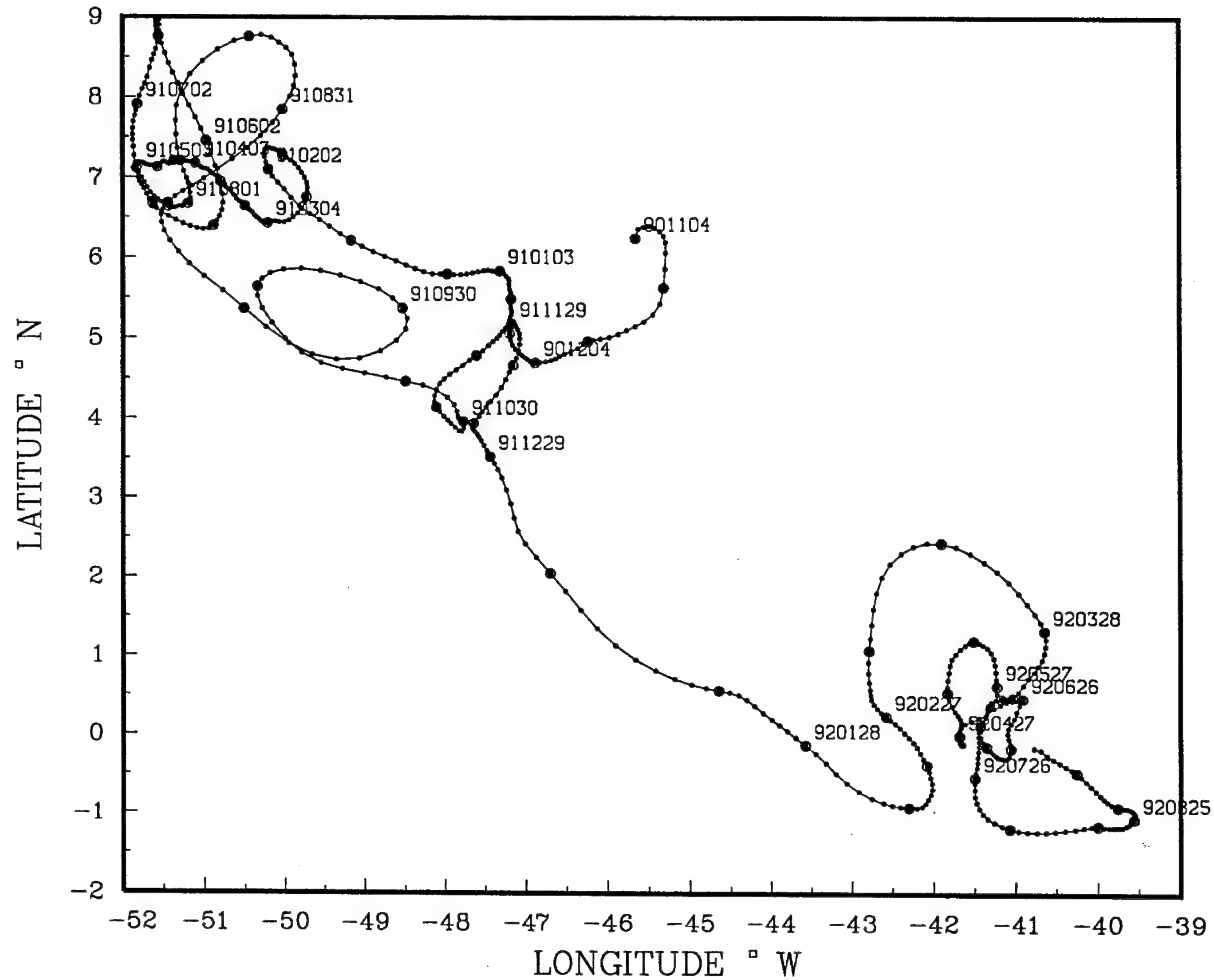


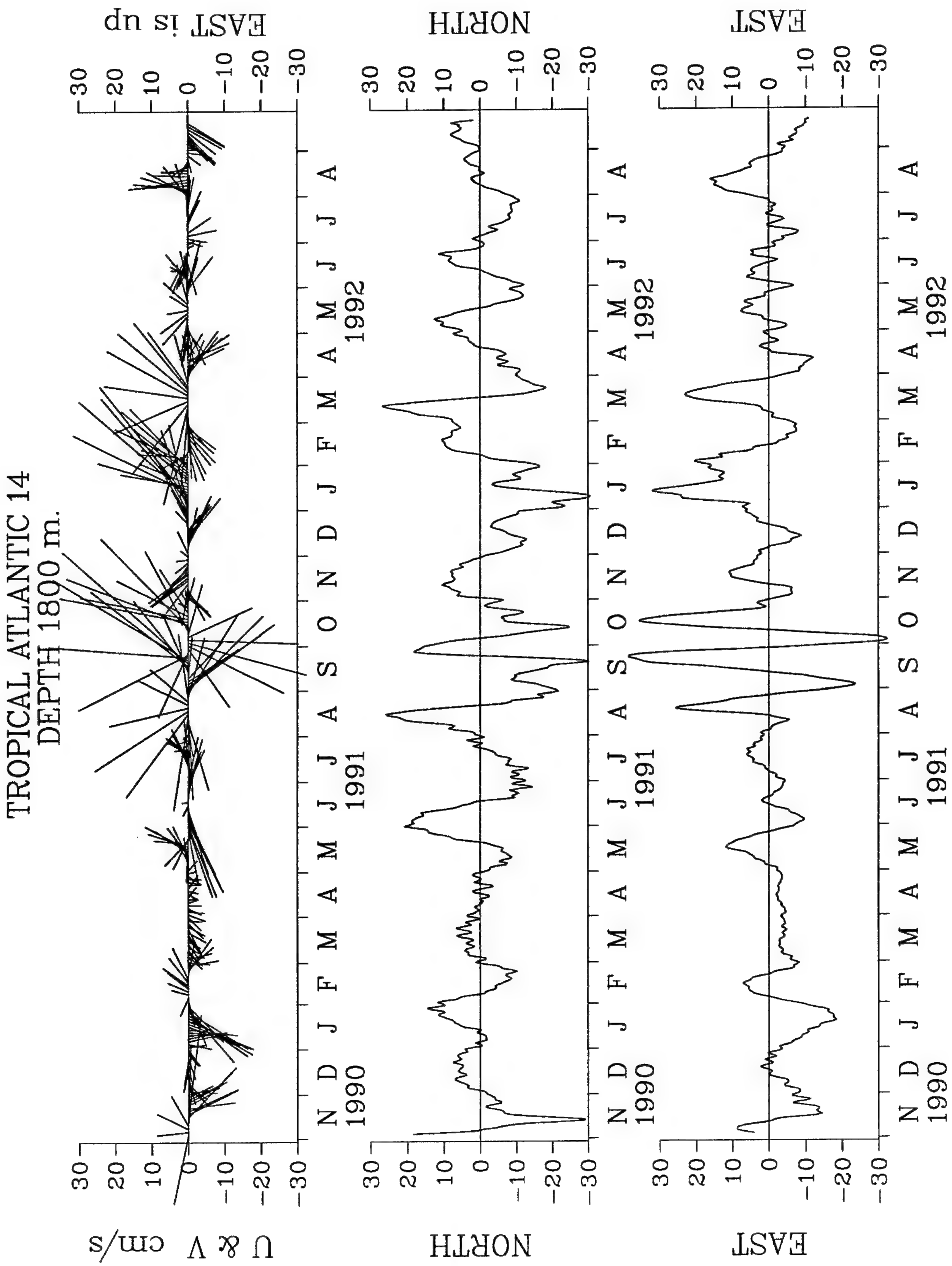


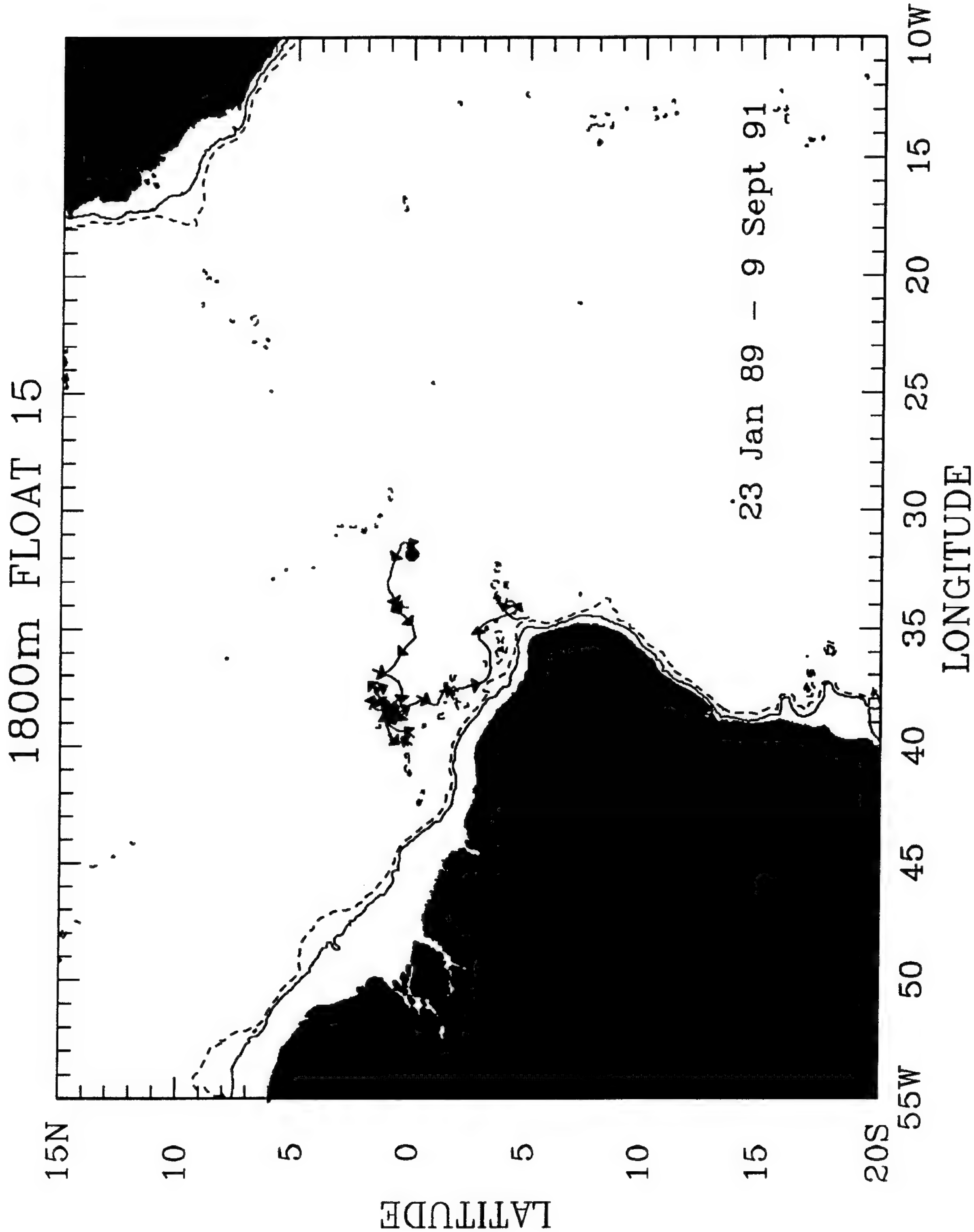
TROPICAL ATLANTIC 13
DEPTH 1800 m.
U & V cm/s
EAST is up
NORTH
EAST
30
20
10
0
−10
−20
−30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992


1800m FLOAT 14
7 Feb 89 – 21 Sept 92
LONGITUDE
LATITUDE
55W
50
45
40
35
30
25
20
15
10W
15N
10
5
0
5
10
15
20S

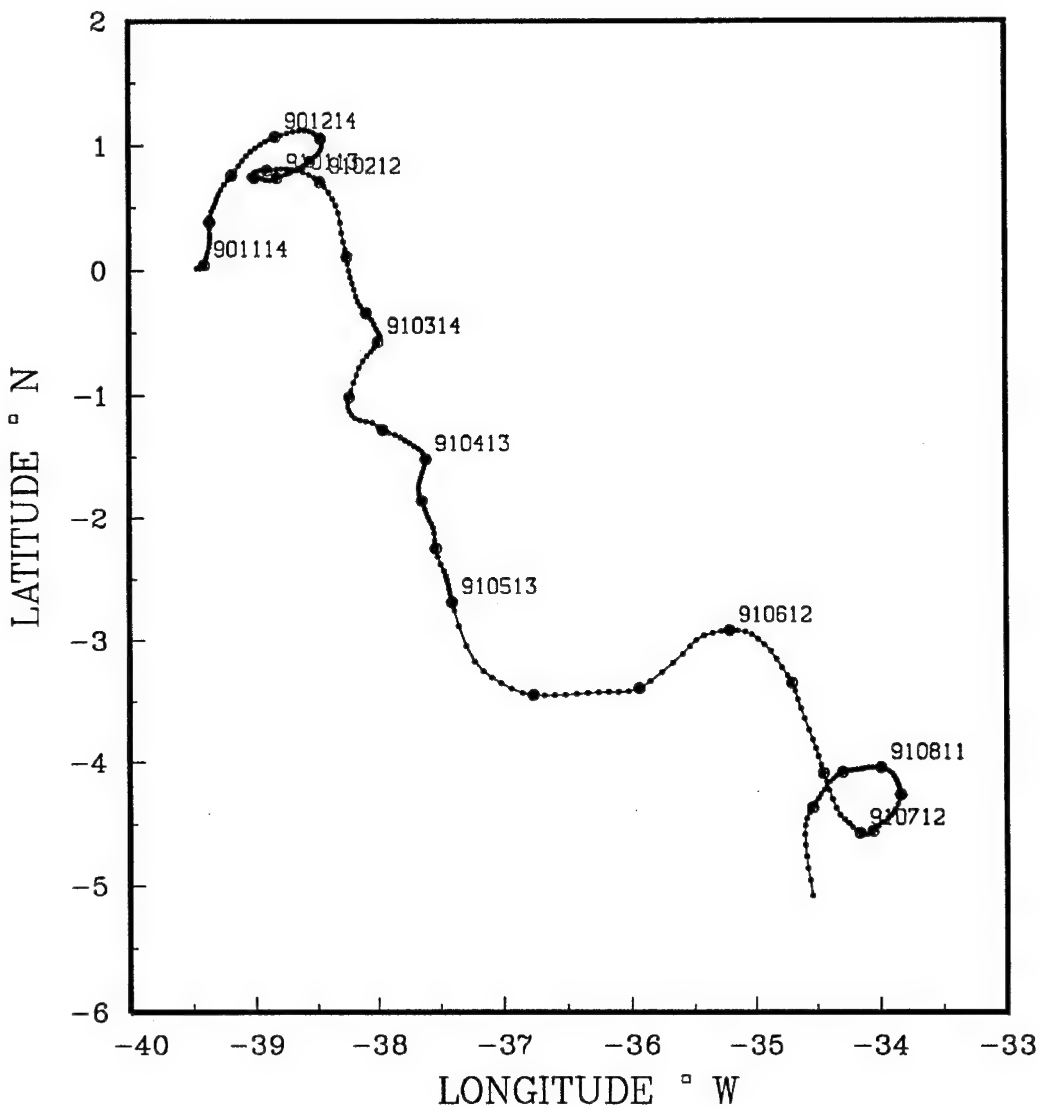
TROPICAL ATLANTIC 14

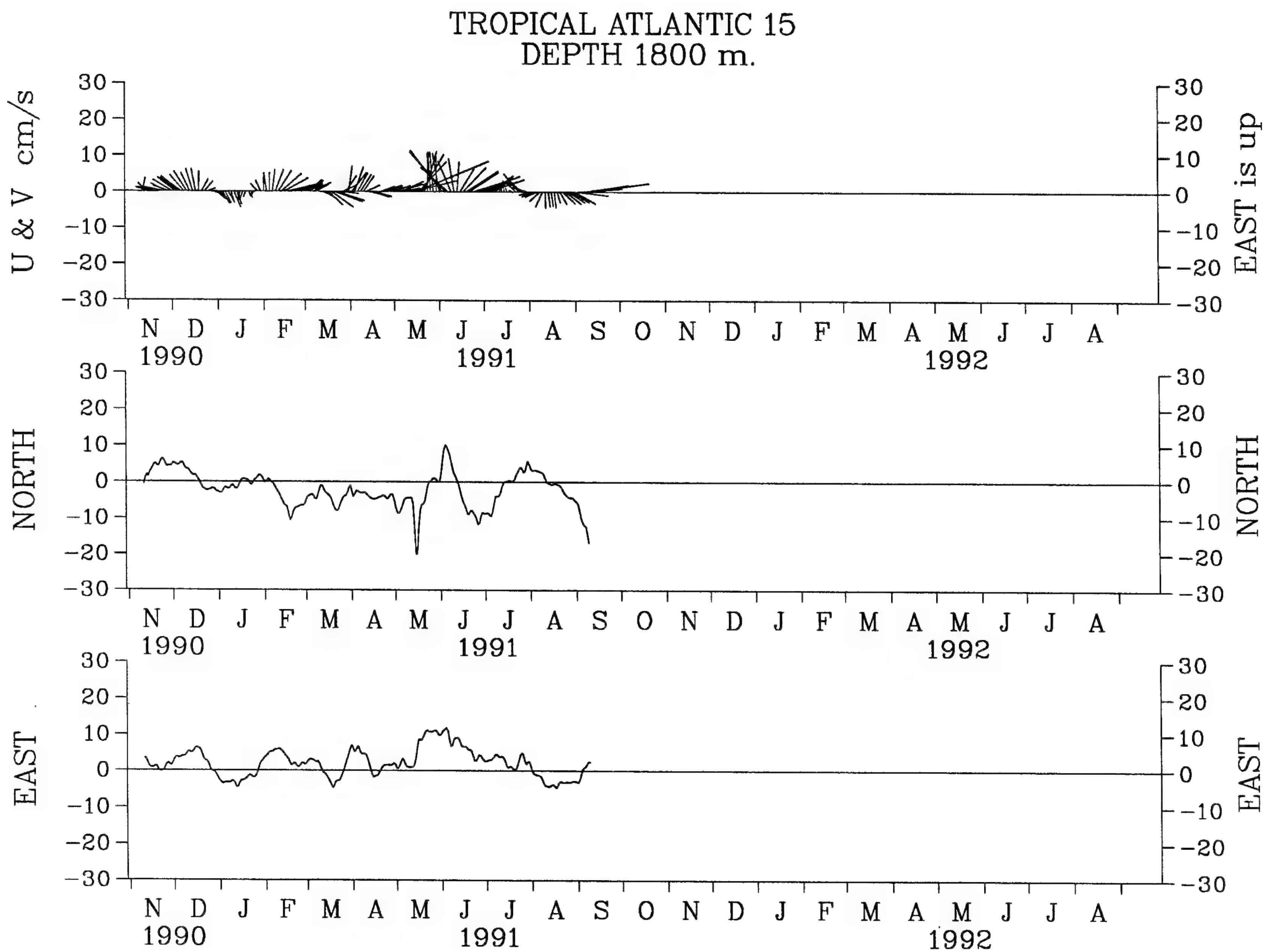



TROPICAL ATLANTIC 14
DEPTH 1800 m.
EAST is up
U & V cm/s
NORTH
EAST
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992
30 20 10 0 −10 −20 −30

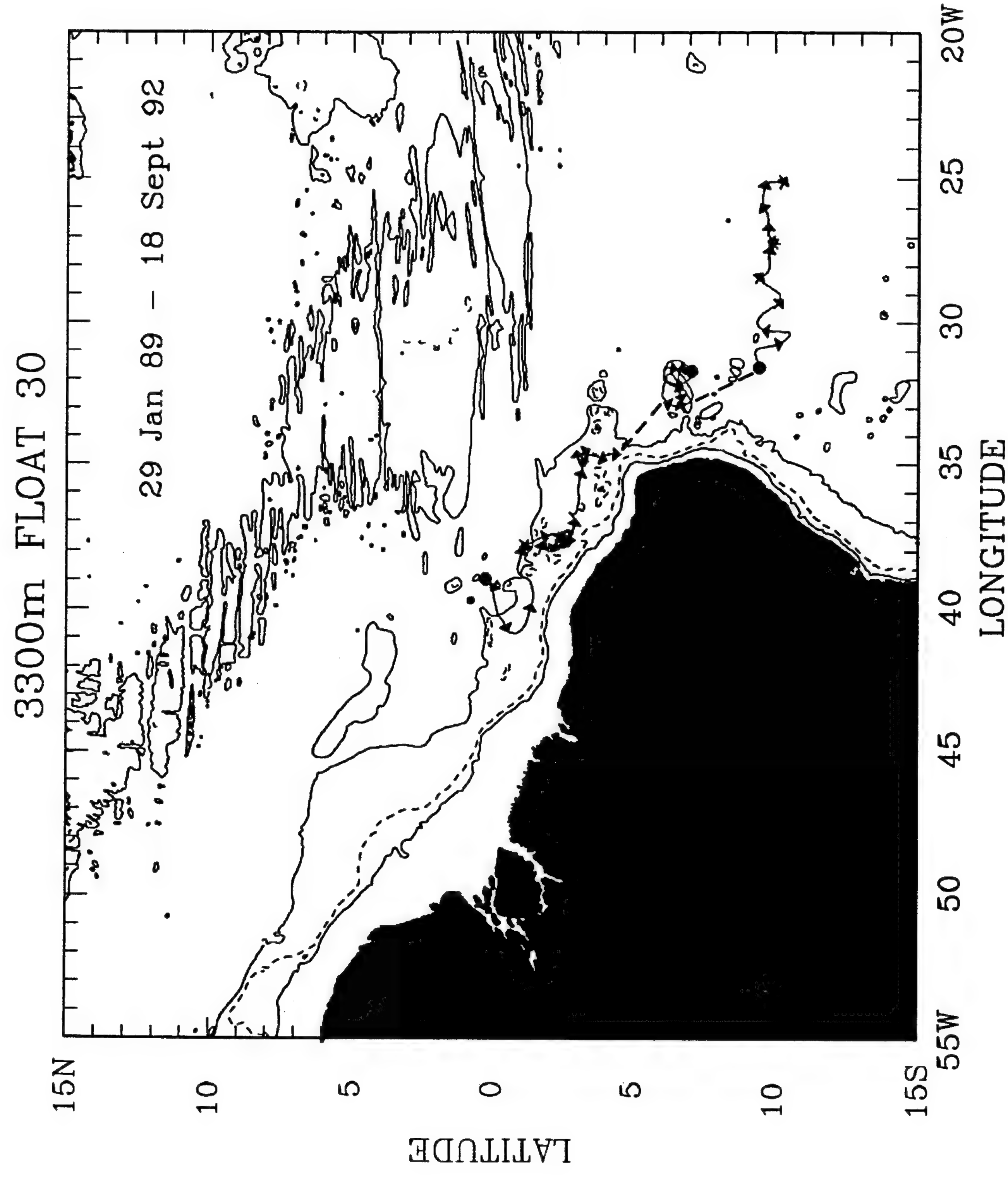

1800m FLOAT 15
23 Jan 89 – 9 Sept 91
LONGITUDE
LATITUDE
15N
10
5
0
5
10
15
20S
55W
50
45
40
35
30
25
20
15
10W

TROPICAL ATLANTIC 15

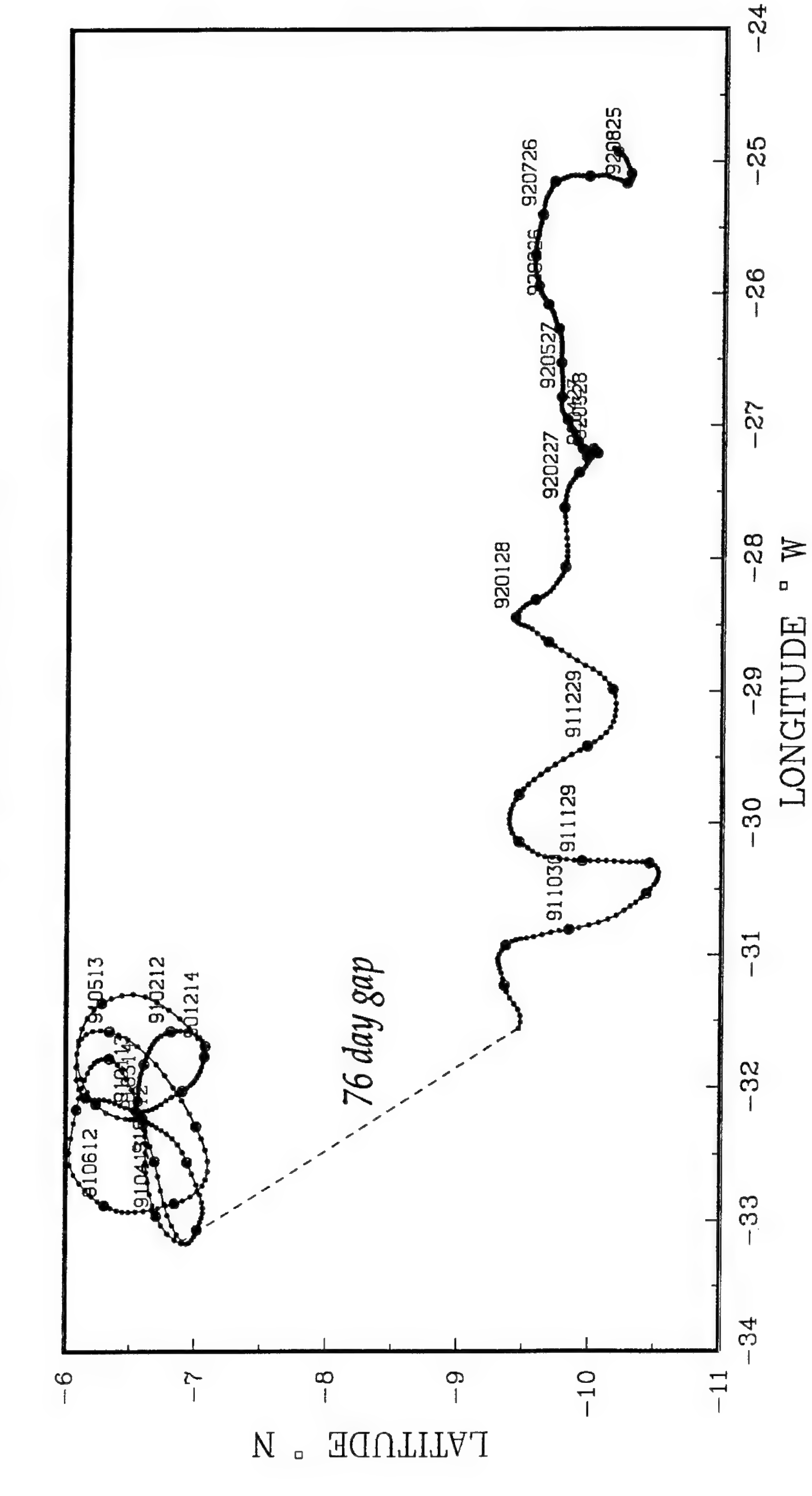


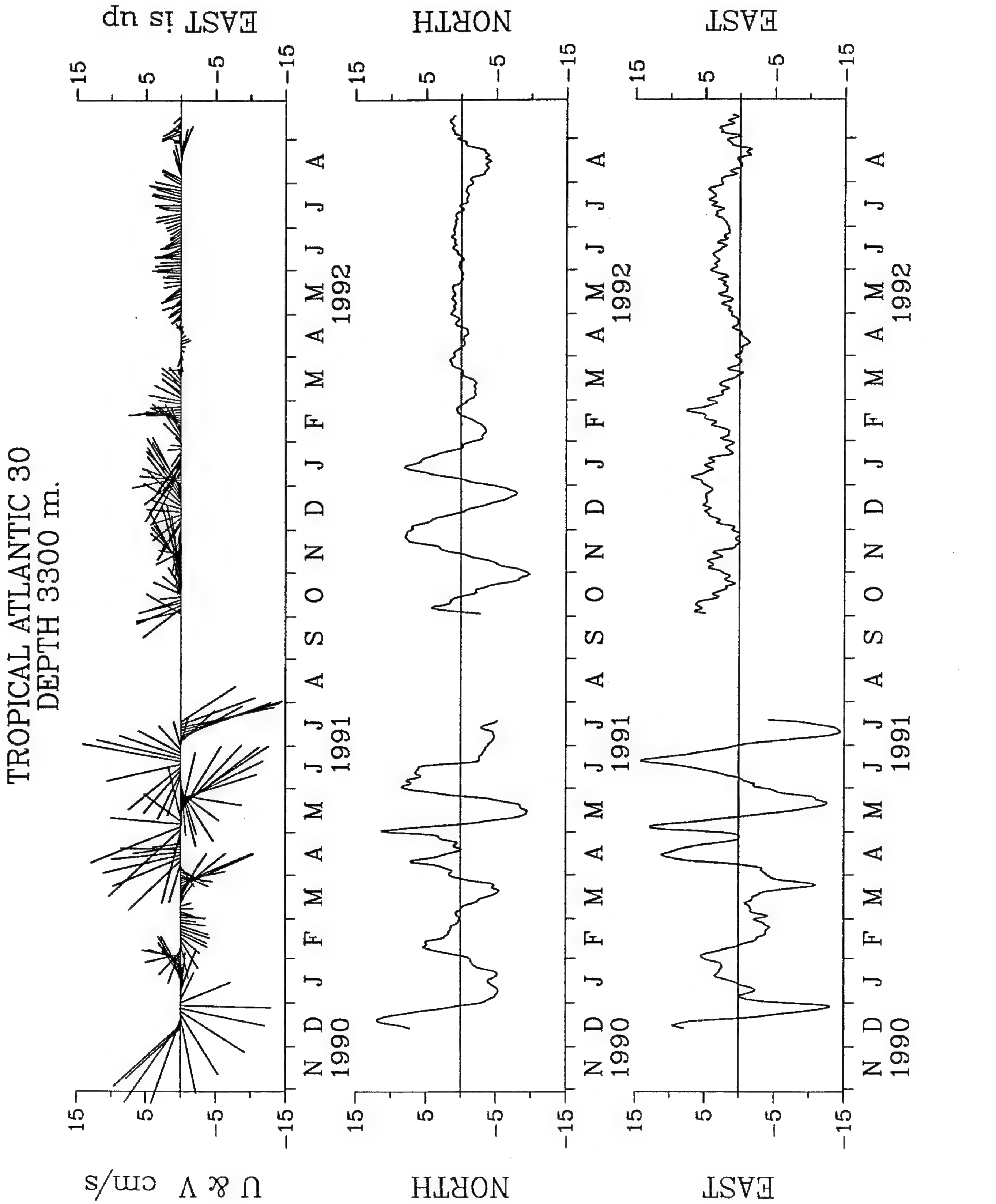


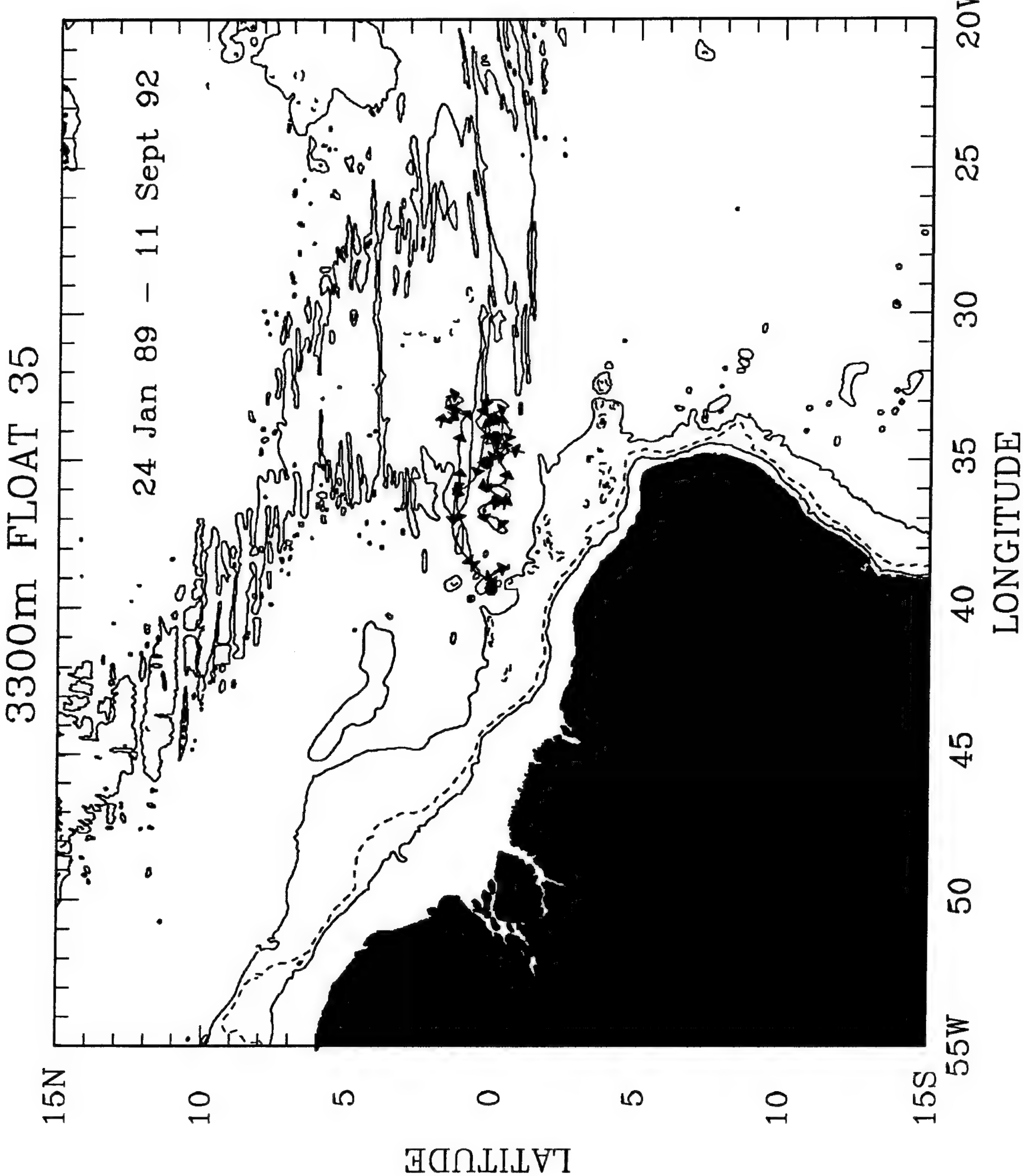
TROPICAL ATLANTIC 15
DEPTH 1800 m.
U & V cm/s
EAST is up
NORTH
EAST
30
20
10
0
−10
−20
−30
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992


3300m FLOAT 30
29 Jan 89 – 18 Sept 92
LATITUDE
15N
10
5
0
5
10
15S
LONGITUDE
55W
50
45
40
35
30
25
20W

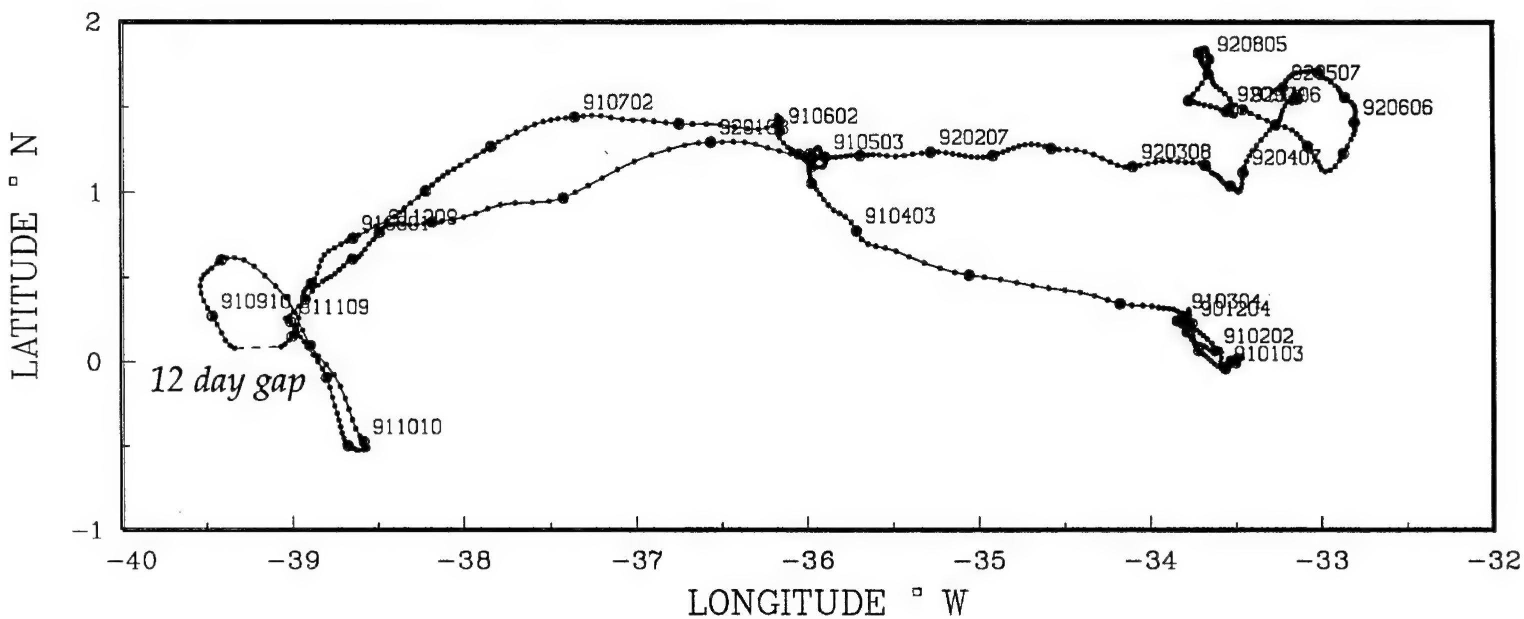
TROPICAL ATLANTIC 30

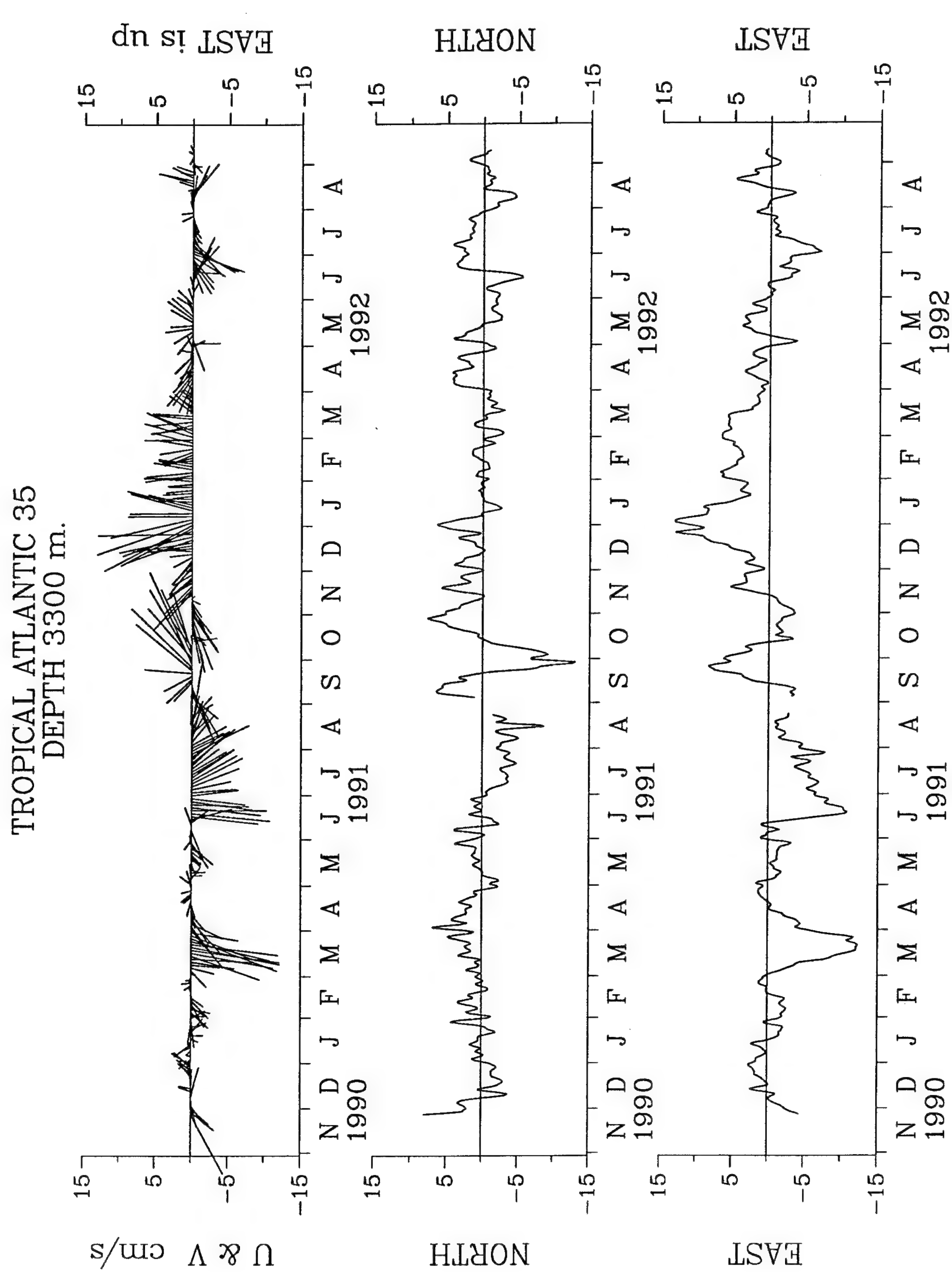


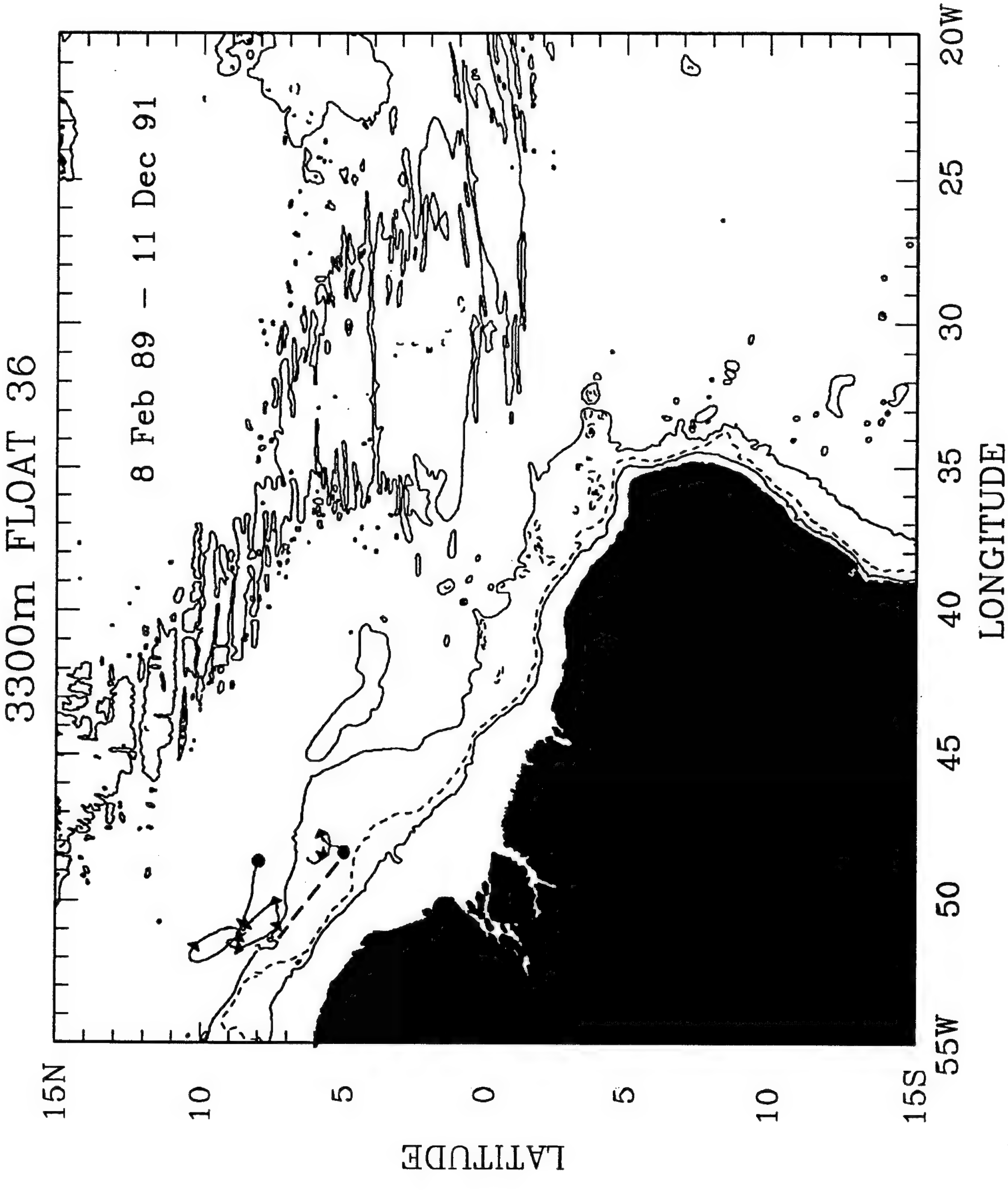

TROPICAL ATLANTIC 30
DEPTH 3300 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992


3300m FLOAT 35
24 Jan 89 – 11 Sept 92
LATITUDE
15N
10
5
0
5
10
15S
LONGITUDE
55W
50
45
40
35
30
25
20W

TROPICAL ATLANTIC 35

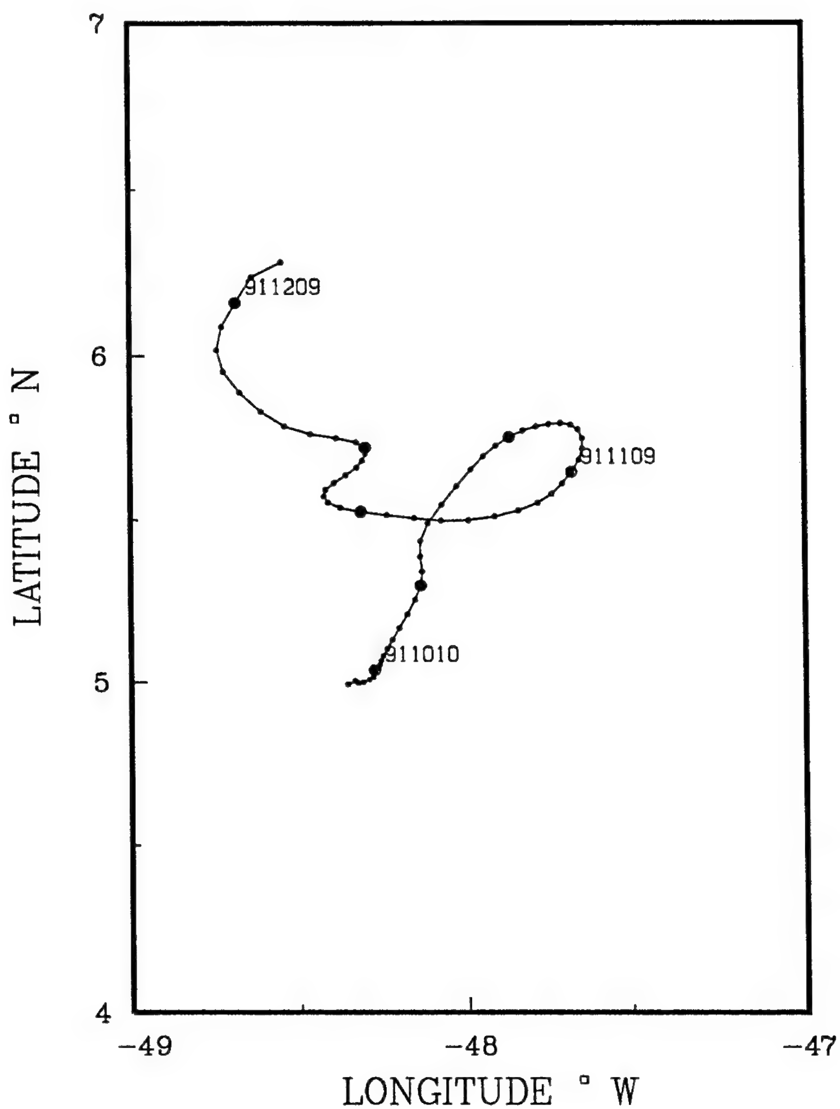


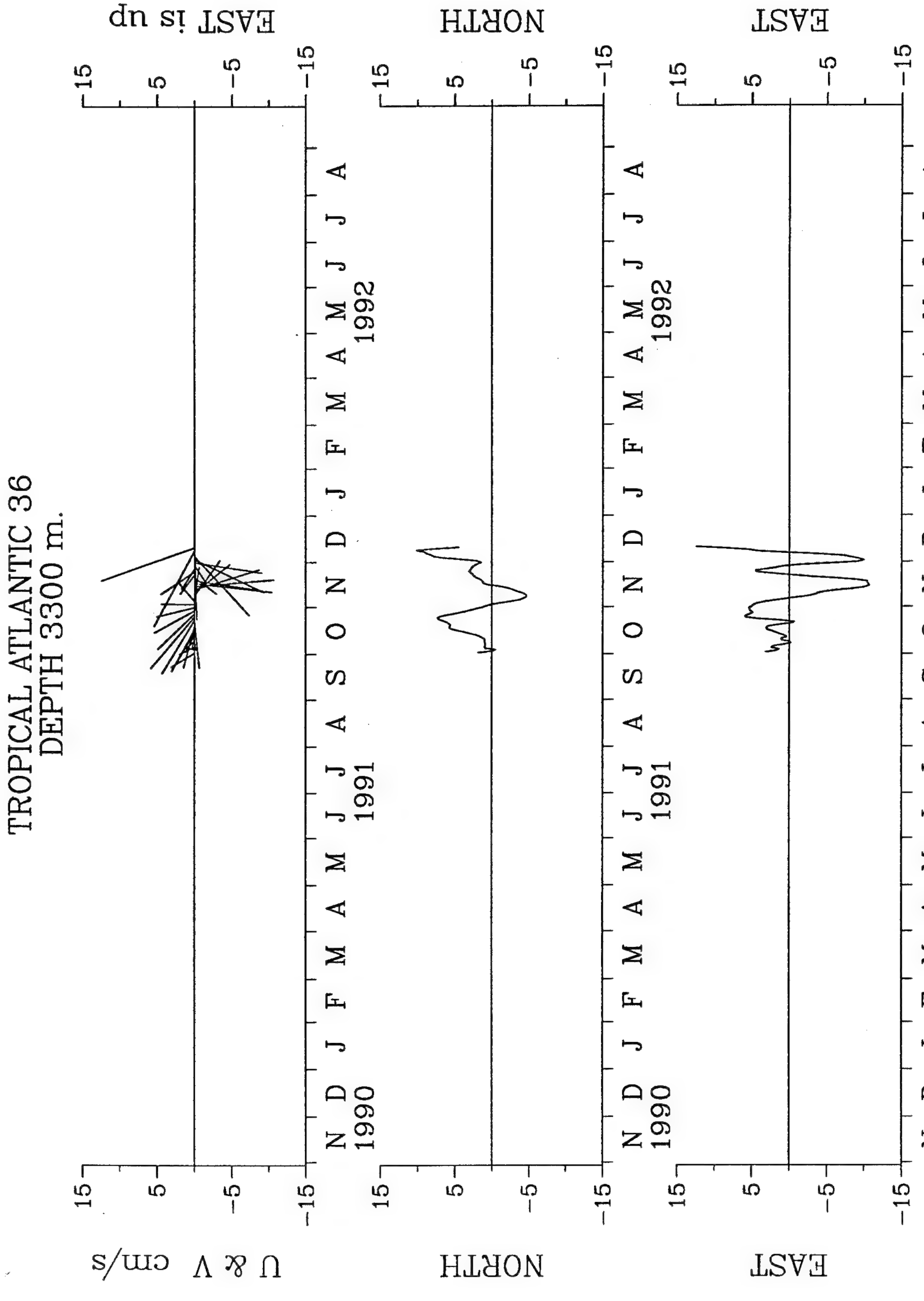

TROPICAL ATLANTIC 35
DEPTH 3300 m.
U & V cm/s
EAST is up
NORTH
EAST
1990
1991
1992

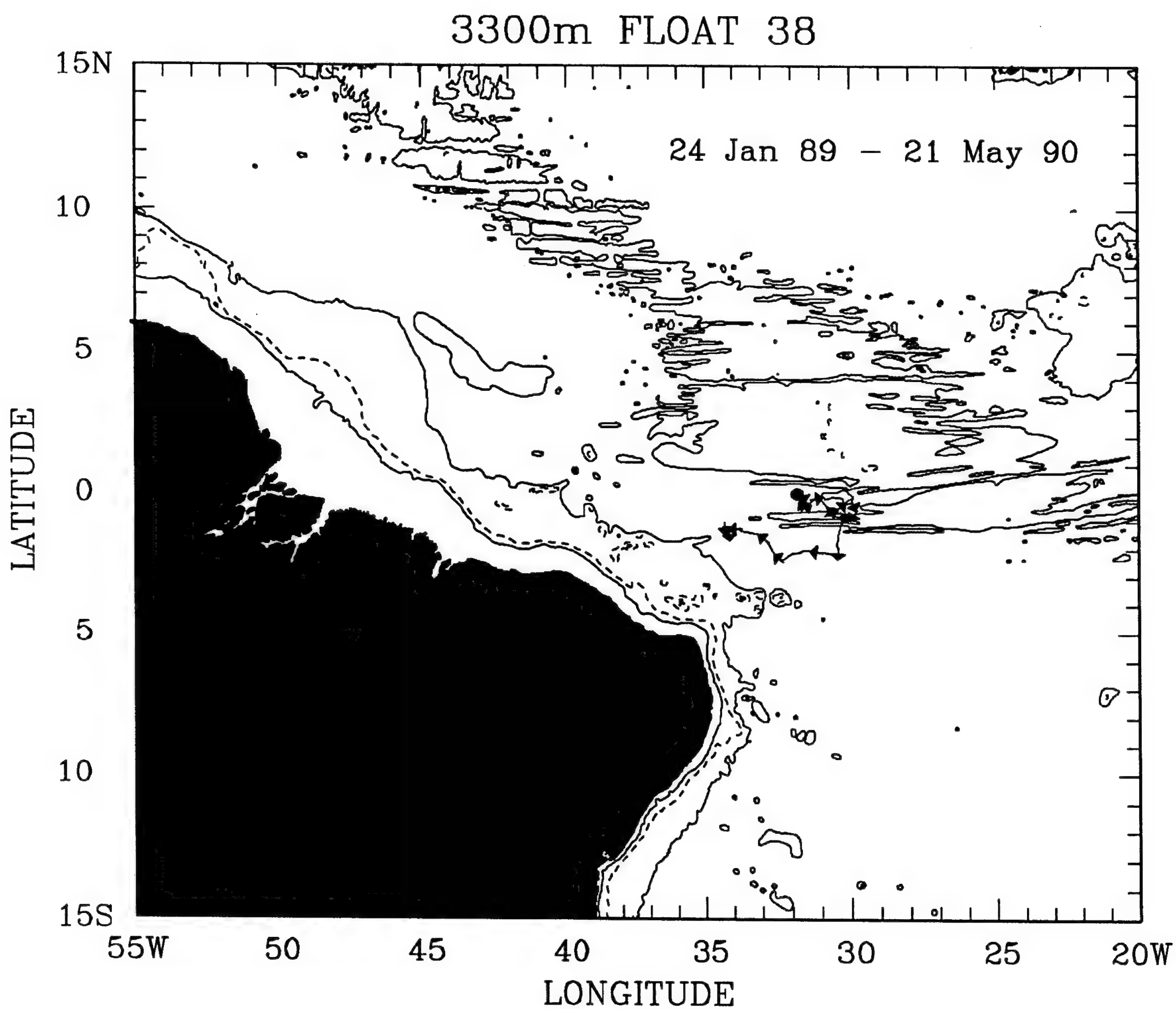


3300m FLOAT 36
8 Feb 89 – 11 Dec 91
LATITUDE
15N
10
5
0
5
10
15S
LONGITUDE
55W
50
45
40
35
30
25
20W

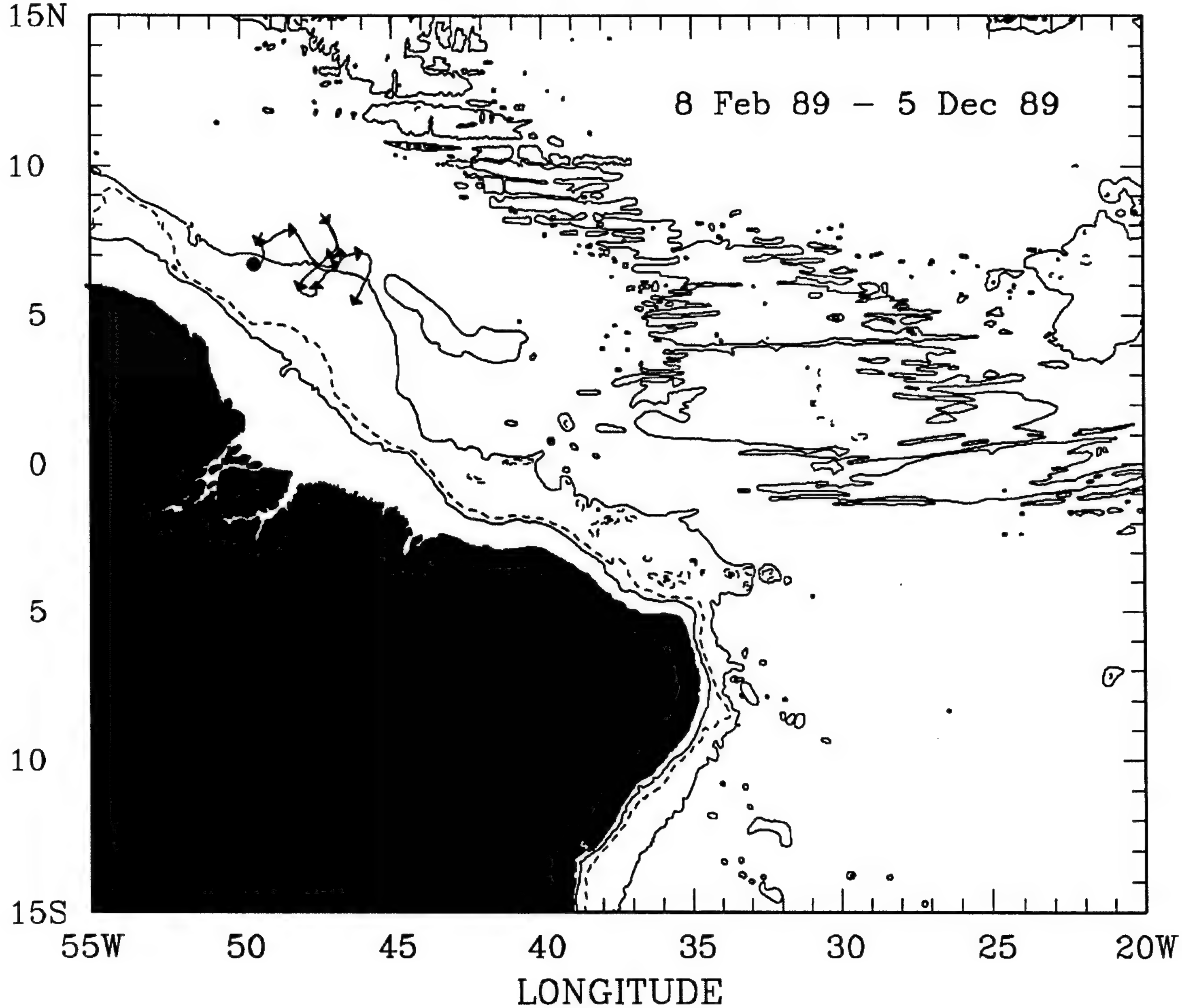
TROPICAL ATLANTIC 36

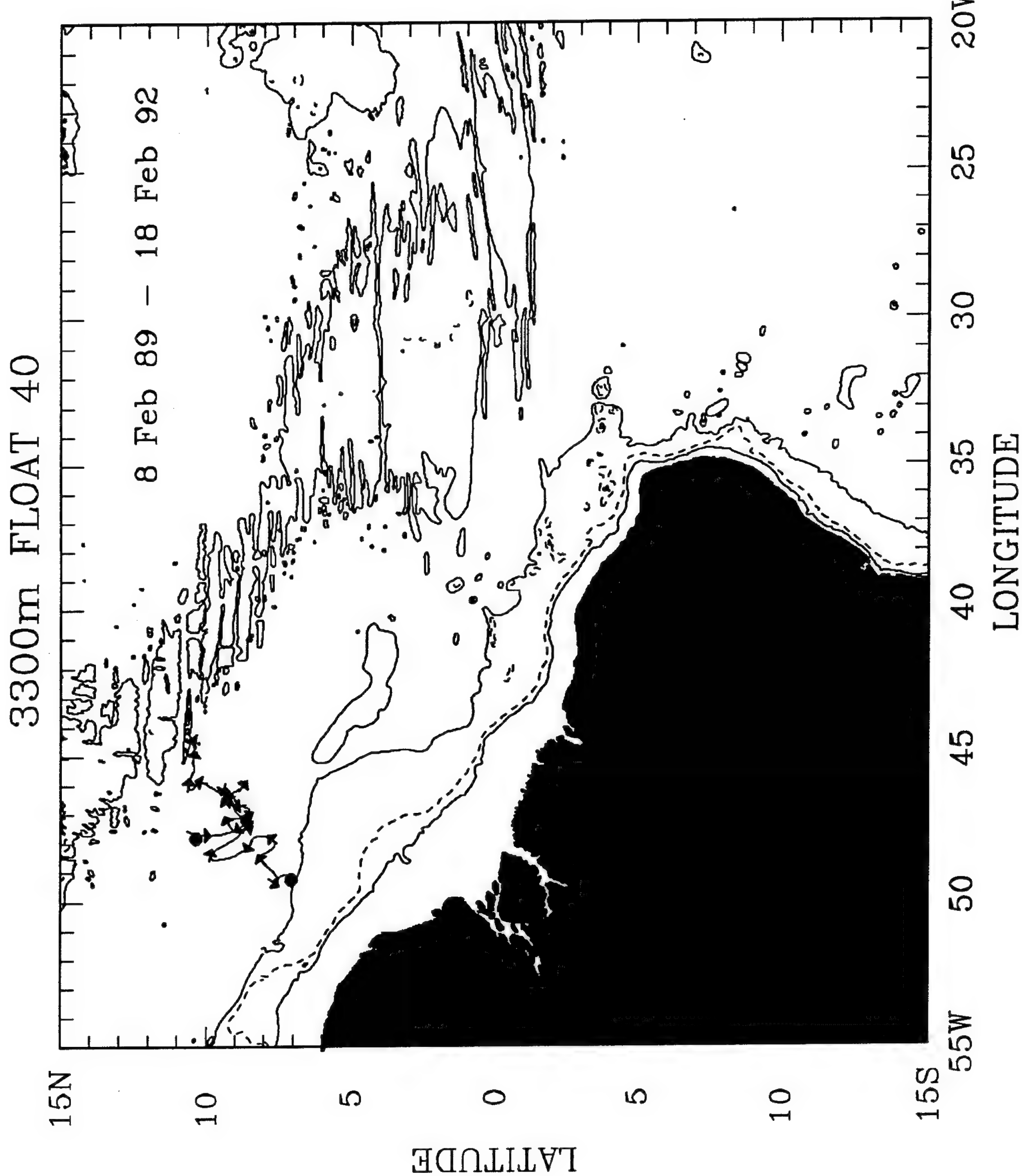



TROPICAL ATLANTIC 36
DEPTH 3300 m.
EAST is up
NORTH
EAST
U & V cm/s
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

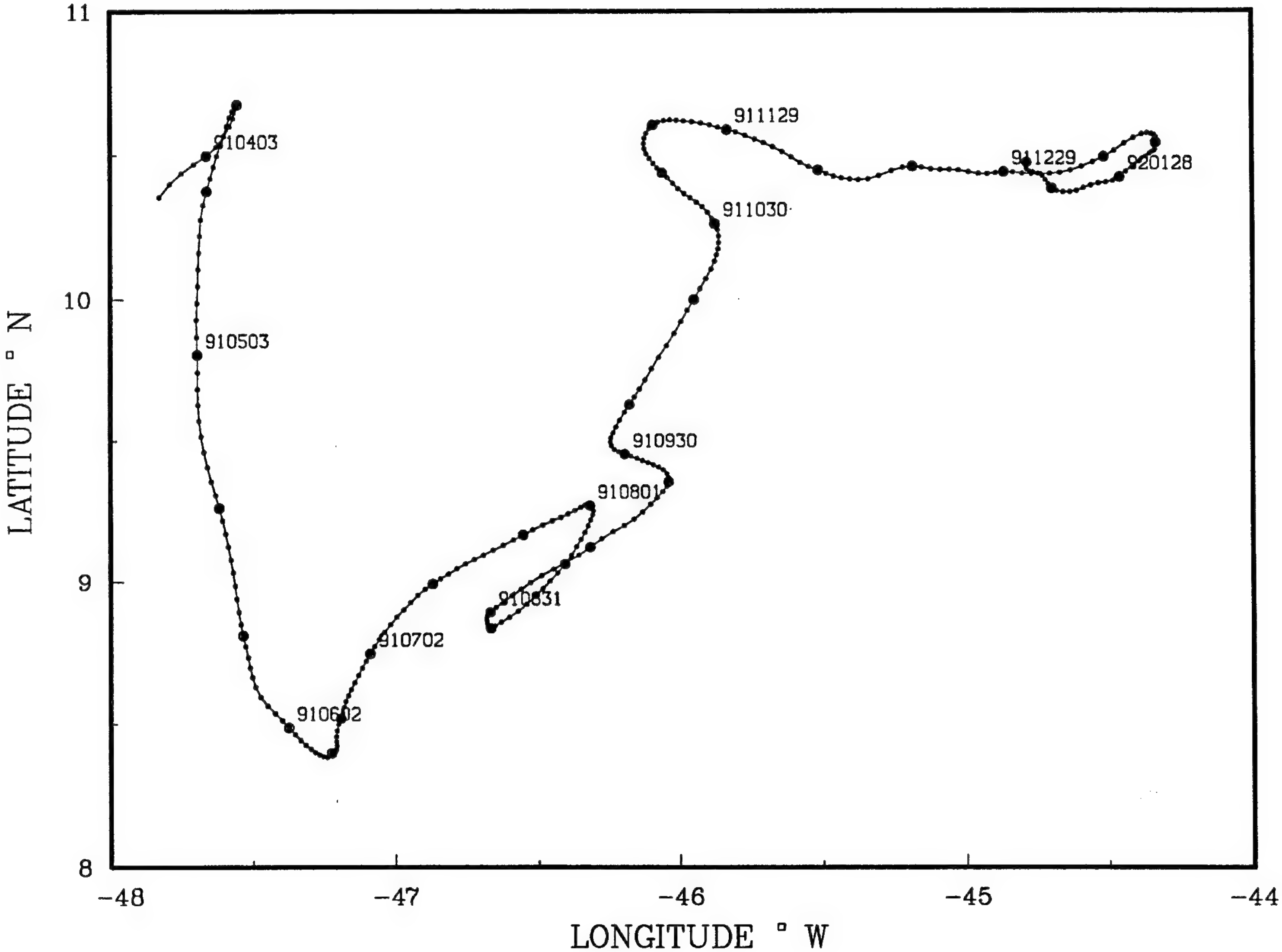

3300m FLOAT 38
24 Jan 89 – 21 May 90
15N
10
5
0
5
10
15S
LATITUDE
55W
50
45
40
35
30
25
20W
LONGITUDE

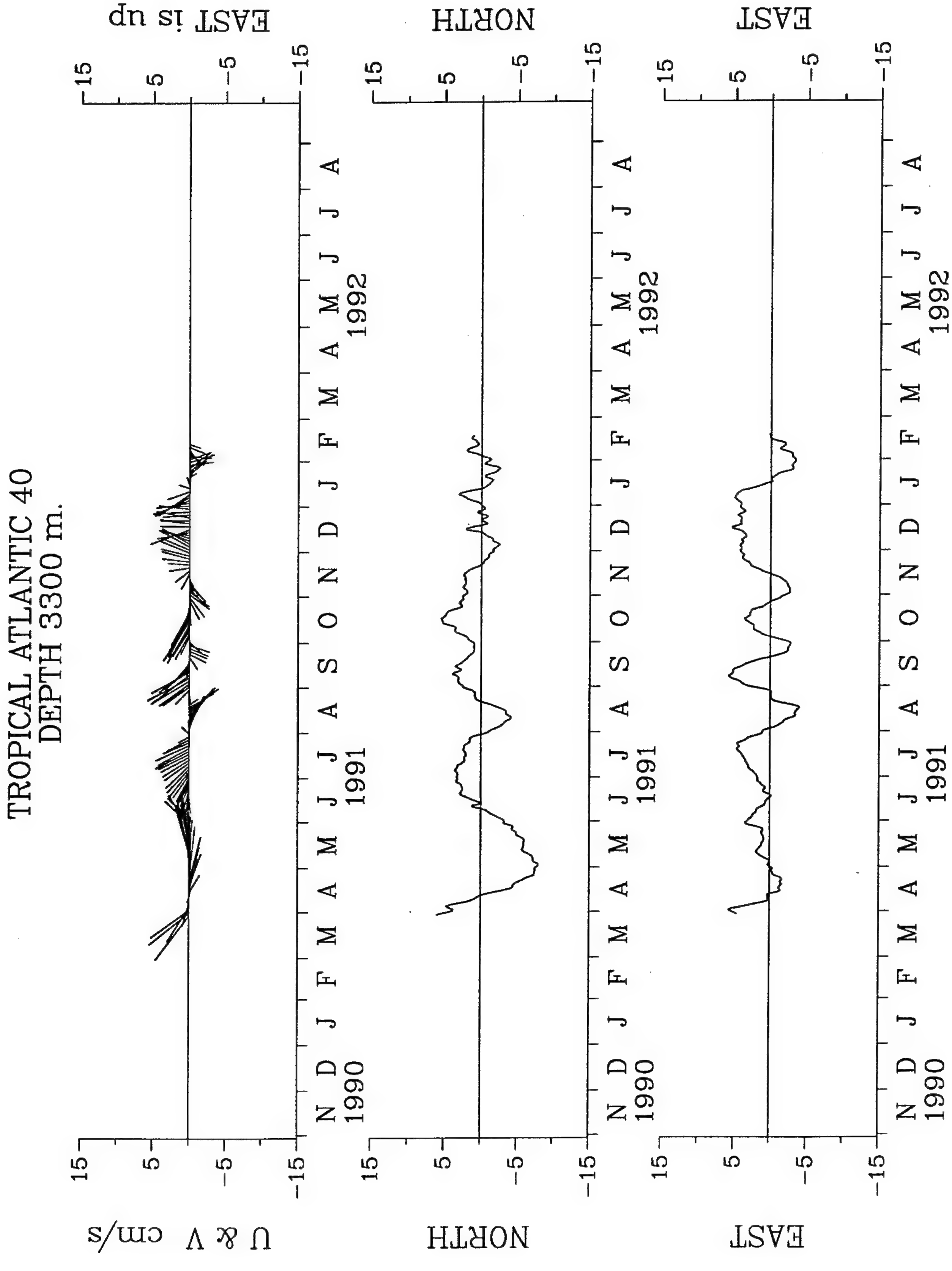
3300m FLOAT 39



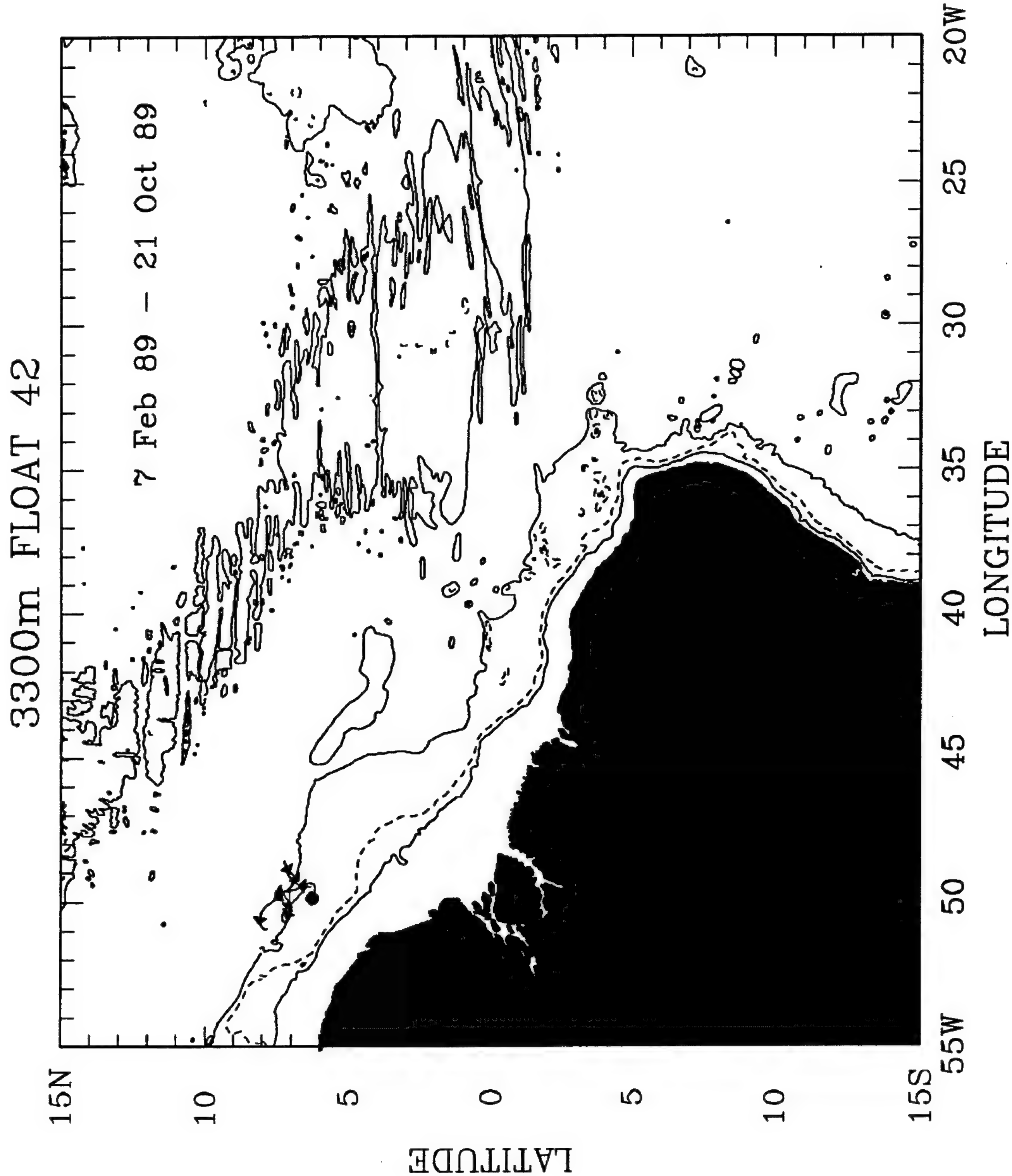

3300m FLOAT 40
8 Feb 89 – 18 Feb 92
LONGITUDE
LATITUDE
55W
50
45
40
35
30
25
20W
15N
10
5
0
5
10
15S

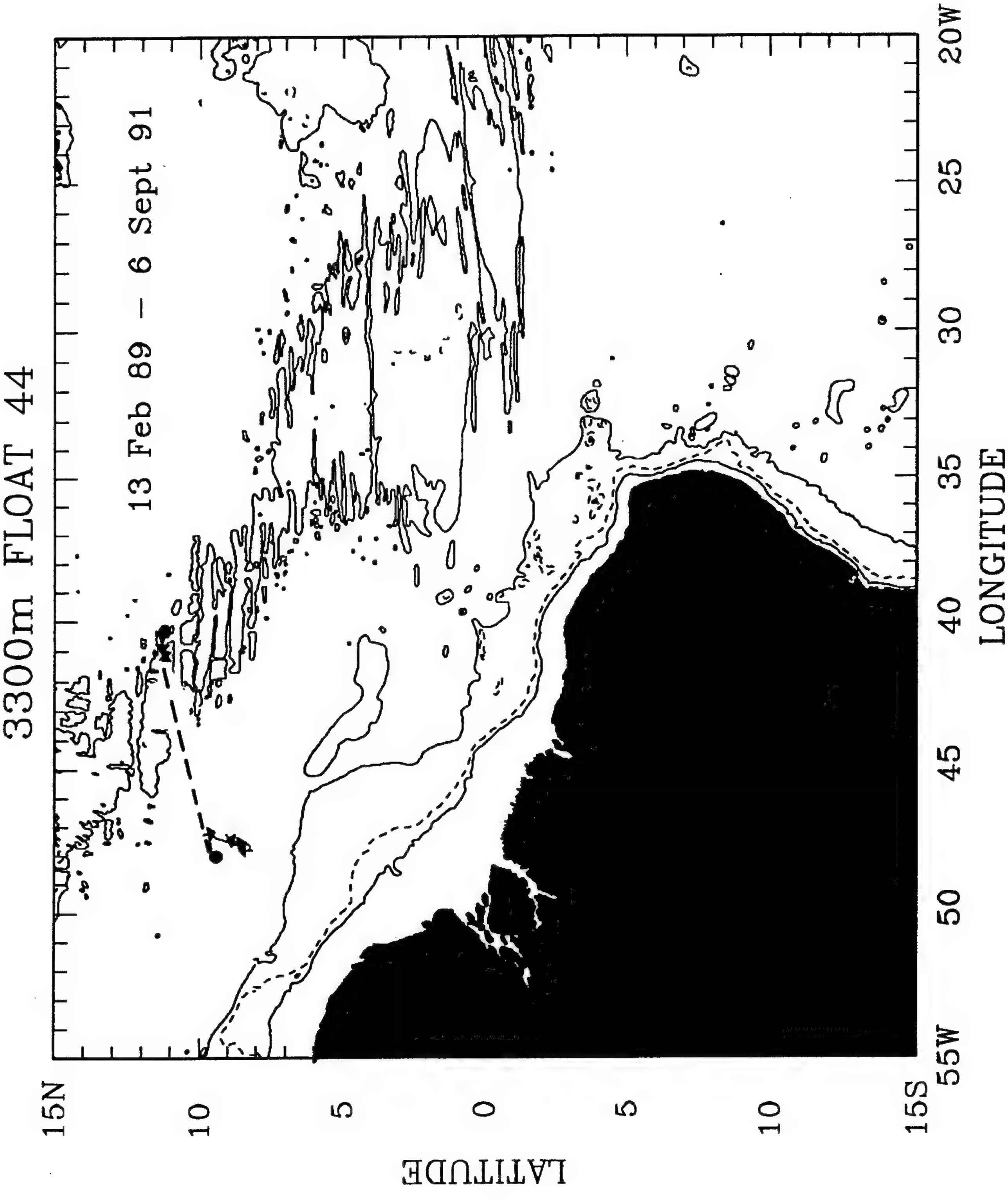
TROPICAL ATLANTIC 40





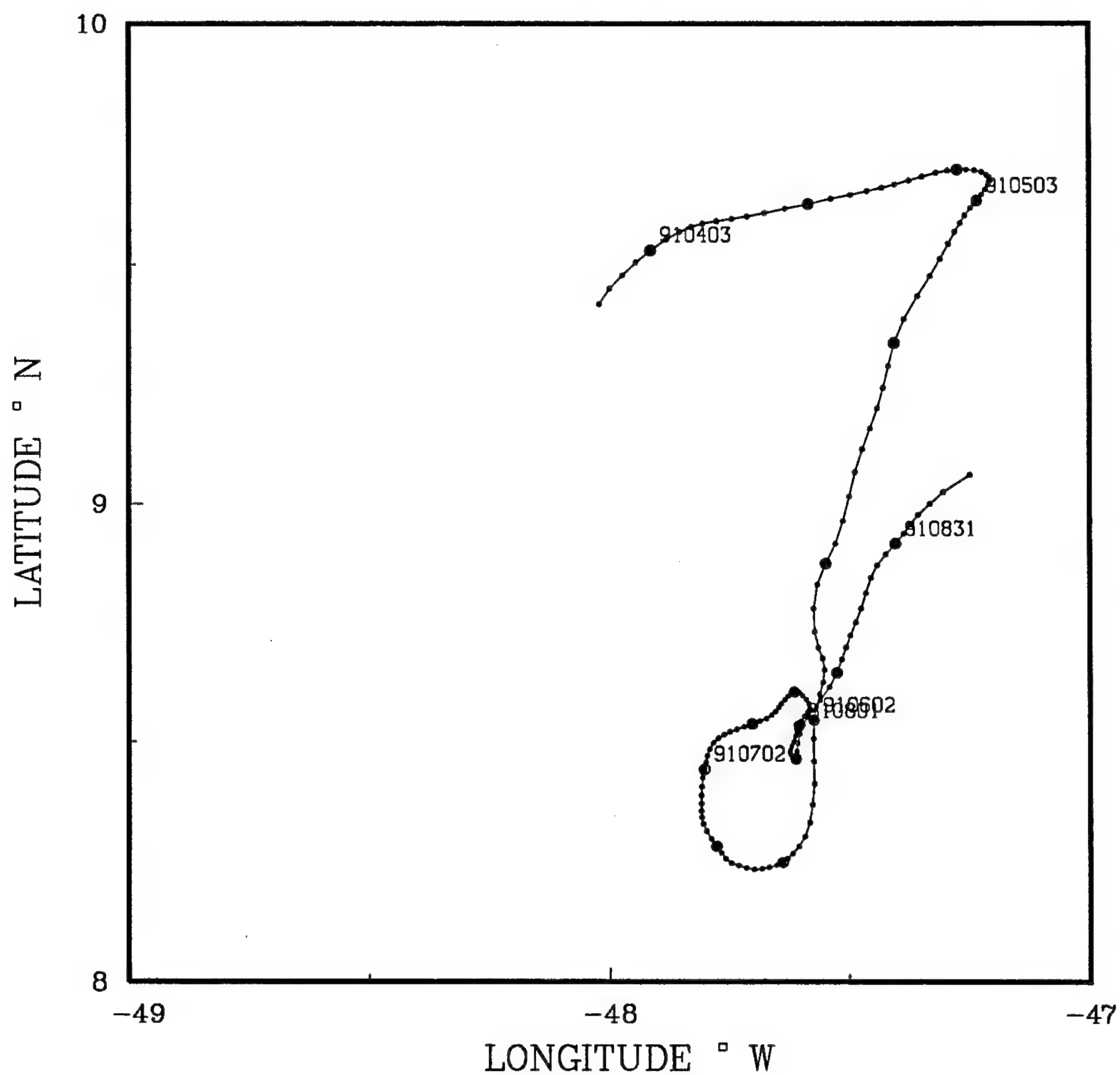
TROPICAL ATLANTIC 40
DEPTH 3300 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
-5
-15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992

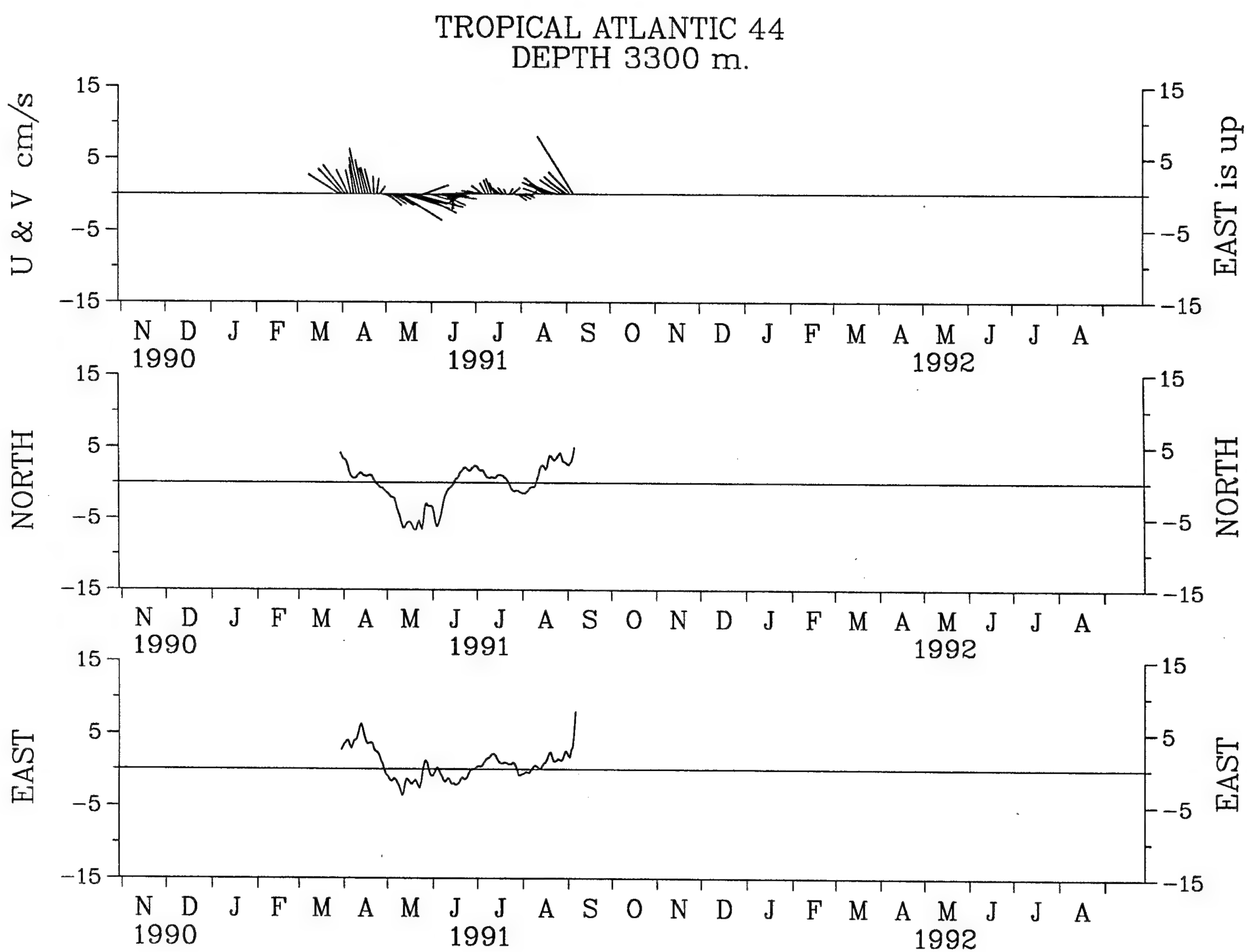

3300m FLOAT 42
7 Feb 89 – 21 Oct 89
LONGITUDE
55W
50
45
40
35
30
25
20W
LATITUDE
15N
10
5
0
5
10
15S

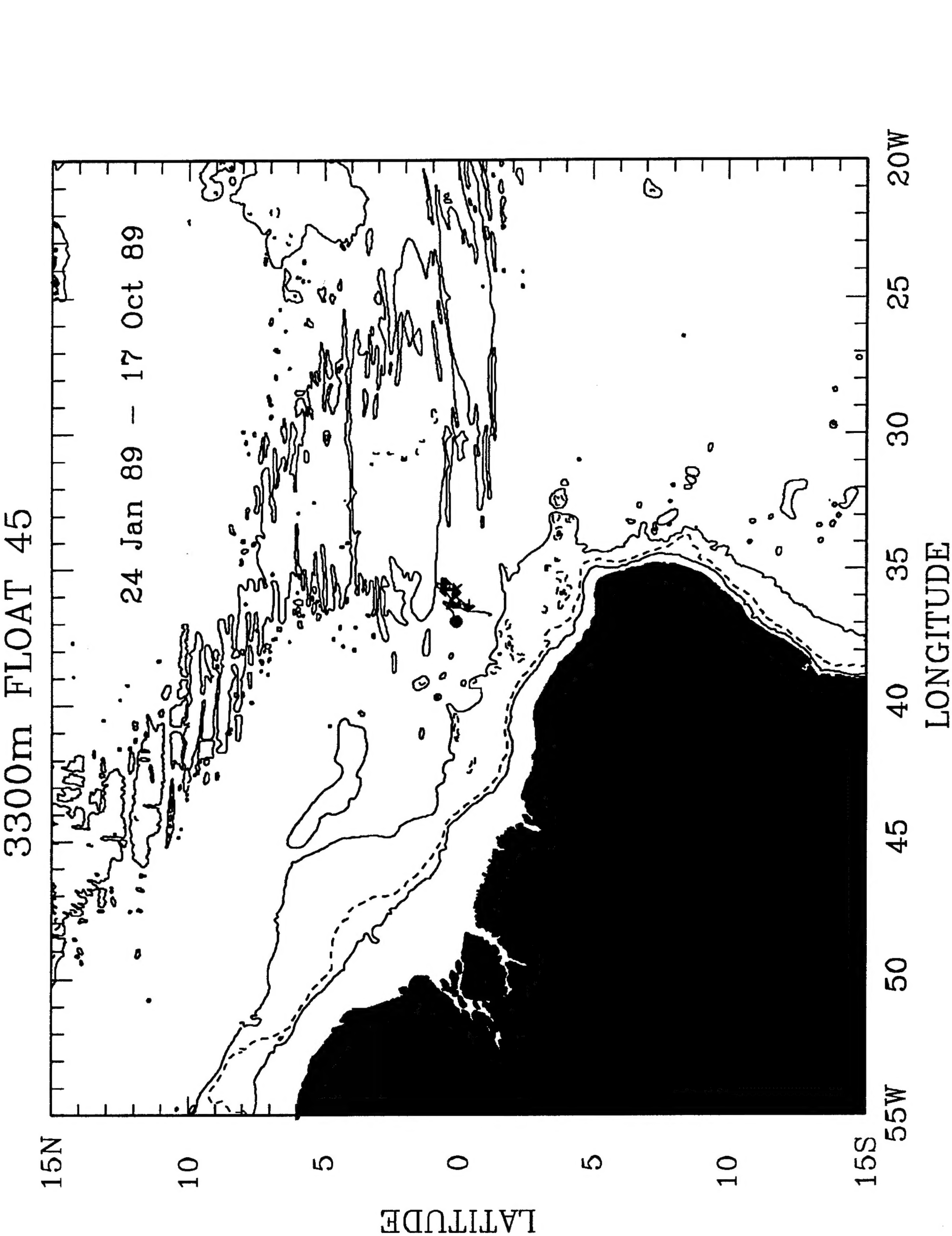


3300m FLOAT 44
13 Feb 89 — 6 Sept 91
LATITUDE
LONGITUDE
15N
10
5
0
5
10
15S
55W
50
45
40
35
30
25
20W

TROPICAL ATLANTIC 44




TROPICAL ATLANTIC 44
DEPTH 3300 m.
U & V cm/s
EAST is up
NORTH
EAST
15
5
−5
−15
N D J F M A M J J A S O N D J F M A M J J A
1990
1991
1992



3300m FLOAT 45
24 Jan 89 — 17 Oct 89
LATITUDE
15N
10
5
0
5
10
15S
LONGITUDE
55W
50
45
40
35
30
25
20W

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16. Abstract (Limit: 200 words)

Neutrally buoyant SOFAR floats at nominal depths of 800 m, 1800 m, and 3300 m were tracked acoustically for 3.7 years in the vicinity of the western boundary and the equator of the Atlantic Ocean. Trajectories and summaries from the whole experiment are shown along with detailed trajectories from the second setting of the listening stations, October 1990 to September 1992. Some highlights are mentioned below.

Trajectories at 1800 m revealed a swift, narrow southward flowing deep western boundary current (DWBC) extending from 7N across the equator. Two floats directly crossed the equator in the DWBC and went to 10S. Two other floats left the DWBC near the equator and drifted eastward. Three floats entered the DWBC from the equatorial current system and drifted southward. No obvious DWBC or swift equatorial currents were observed by the 3300 m floats.

The 800 m floats plus some surface drifters measured seven anticyclonic eddies as they translated northwestward along the coast of South America in a band from the equator to 12N. One of the floats (28) entered the Caribbean where tracking stopped. This float was again tracked as it drifted across the mid-Atlantic Ridge and entered the Canary Basin near 34N 28 W after a gap of 2.7 years. We infer that this float went westward through the Caribbean and northeastward in the Gulf Stream. Float 17 drifted northward from 10N to 22N in an eastern boundary current off the coast of West Africa. Floats between 6N-6S (roughly) drifted long distances zonally in the equatorial current system.

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